Distribution: for publication

Final report

LOT 32 / –Ecodesign of Window Products
TASK 4 - Technology

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3 June 2015

Specific contract No ENER/C3/2012-418-Lot1/03
Multiple framework service contract No ENER/C3/2012-418-Lot 1

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SUMMARY

Product description

Windows are generally understood as building components that admit (day)light and may also admit ventilation air to the spaces they (partly) enclose. In general they consist of a 'frame' and 'glazing'.

The main components of a window are:

- The glazing (transparent area)
- Frame profiles
- Hardware (mechanic to open the window)
- Gaskets (serve for air tightness and water tightness)

Considering, that windows are a combination of the above stated components and that for each component there are a variety of technical solutions/products fulfilling different requirements it is clear that there is a huge range of different window solutions.

Keeping in mind that approx. 70% of the window area is transparent it is unquestioned that the window performance (energy usage in the use phase) is mainly influenced by the glazing. Therefore in the past, major improvements of windows have been achieved by improving the glazing.

Nevertheless also the energy performances of the frames were improved significantly within the last years.

For the transparent area of the window different glazing products are available:

- Single glazing
- Double glazing
- Double glazing (with low e coating and gas filling)
- Triple glazing (with low e coating and gas filling)

The energy performances of these glazing products, thermal transmittance (U_g value) and the solar energy transmittance (g-value) differ significantly.

The following frame materials are commonly used for windows:

- Metal (in general Aluminium)
- Plastics (in general PVC)
- Wood (also in combination with an exterior cladding)

The frames for roof windows are made of wood, PU or PVC. The exterior of the frame is metal-clad as standard. In general the energy related performances of frames (thermal transmittance U_f) do not differ significantly when comparing different frame materials. Similar U_f values can be achieved with all frame materials.

Best available technology:

To evaluate the best available technology calculations of the energy performance of different design options were made. The normative basis for these calculations was ISO 18292 and EN 13790 and the method applied was based on the 'adiabatic' method, applied to both a 'single room' and a 'single family house'. Three different climate conditions (North, Central, and South) were addressed. Additionally some boundary conditions (e.g. window area/floor area, heat capacity, internal heat load, U-value of the envelope) were varied to study the influence of these parameters on the result.

The results lead to the following conclusions (based on the total energy performance):

- For climate North and Central the BAT is for all investigated different building approaches (single room, single family house): Openable window with very low U-value and high g-value, moveable external shutter
- For Climate South: The BAT differs depending on the building approach. For the single room approach the BAT is an openable window with low U-value and low g-value, moveable external shutter/sun shading device. For the approach considering a single family house the BAT is an openable window with very low U-value and high g-value, moveable external shutter
- The proportions of the heating energy and the cooling energy to the combined energy are influenced by the ratio of heat gains to the heat losses of the building. For buildings with low heat losses, e.g. low U-values of the building envelope, compact buildings (multi family houses => single room approach), no ventilative cooling the proportion of the cooling energy is increasing compared to buildings with higher heat losses.

Small variations of the boundary conditions do not lead to significant different ranking of the investigated design options. Therefore the BAT definition can be used for building, where the assumed boundary conditions are representative and for buildings where the boundary conditions only vary within certain limits. Residential buildings are fulfilling these requirements in general.

Non-residential buildings can differ significantly in the relevant parameters (e.g. ratio of the window area to floor area; internal loads, usage etc.). This has in general a significant impact on the energy performance of the investigated design options and on the ranking. Therefore it is not possible at least very hard to define a representative BAT for non-residential buildings. To find the BAT or best solution for such buildings has to be answered by the assessment of a holistic approach, considering all the relevant parameters of the building.

Production, distribution, end of life

Analysing the existing Life cycle assessments for windows the following conclusions are obvious:

- The energy demand for the production of windows as also the environmental impacts do not differ significantly as a function of the frame material.
- The energy demand and the environmental impacts of windows for the use phase is the major proportion in a full life cycle assessment.

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LIST OF ABBREVIATIONS & ACRONYMS

AP	Acidification Potential
BAT	Best Available Technology
BNAT	Best Not yet Available Technology
BOM	Bill of Materials
CA	Concerted Action
C&D	Construction and demolition waste
CENELEC	European Committee for Electro technical Standardization
CEN	European Committee for Normalisation
CPD	Construction Products Directive
CPR	Construction Products Regulation
EN	European Norm
EOL	End Of Life
EOTA	European Organisation for Technical Assessment in the area of construction products
EP	Eutrophication Potential
EPBD	Energy Performance of Buildings Directive
EPD	Environmental Product Declaration
EPS	Expanded Polystyrene
ETAG	European Technical Approval Guidelines
EU	European Union
EuP	Energy using Products
ErP	Energy related Products
FDES	Fiches de Déclaration Environnementale et Sanitaire (from the French EPD system)
GWP	Global Warming Potential
HM	Heavy Metals
IAQ	Indoor Air Quality
JRC	Joint Research Centre
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
MEErP	Methodology for Ecodesign of Energy related Products
MEEuP	Methodology for Ecodesign of Energy using Products
MEPS	Minimum Energy Performance Standard
MS	Member State
NEEAP	National Energy Efficiency Action Plan
NMVOC	Non Methane Volatile Organic Compound
NZEB	Nearly Zero Energy Building
ODP	Ozone Depletion Potential

ODS	Ozone Depleting Substance
OEF	Organisational Environmental Footprint
PEF	Product Environmental Footprint
PEFCRs	Product Environmental Footprint Category Rules
PM	Particulate Matter
POP	Persistent Organic Pollutants
POCP	Photochemical Oxidant Creation Potential
PRODCOM	PRODuction COMmunautaire
RES	Renewable Energy Sources
RoHS	Restriction of the use of certain Hazardous Substances in electrical and electronic equipment
CI/SfB	Construction Index/Samarbetskommitten for Byggnadsfrago
SME	Small and Medium sized Enterprise
TC	Technical Committee
TR	Technical Report
VITO	Flemish Institute for Technological Research
VOC	Volatile Organic Compounds

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CHAPTER 1 PREFACE

This report has been prepared by Van Holsteijn en Kemna BV (VHK) in collaboration with ift Rosenheim and the Flemish Institute for Technological Research (VITO), under the Multiple Framework Contract related to preparatory studies and related technical assistance on specific product groups (ENER/C3/2012-418-Lot 1), and in response to the Terms of Reference included in the Contract for the "Ecodesign study with regard to Windows".

The subject of this report falls under the general context of sustainable industrial policy which aims to foster the development of products with less environmental impacts.

Directive 2009/125/EC ("Ecodesign Directive") is the cornerstone of this approach as it establishes a framework for the setting of Ecodesign requirements for energy-related products (ErPs) with the aim of ensuring the free movement of these products within the internal market. Directive 2009/125/EC targets ErPs as these account for a large portion of the consumption of energy and natural resources, and a number of other environmental impacts, in the Community, in particular during their use phase.

Directive 2010/30/EC on the energy labelling of ErPs is complementary to the Ecodesign Directive as it requires (a.o.) information on the impact by these products on the use of essential resources to be provided to consumers at the point of sale.

Any measure prepared under these directives must be preceded by a study or assessment ('preparatory study') that sets out to collect evidence and stakeholder input, explore policy options and describe the recommended policy mix (ecodesign and/or labelling and/or self-regulation measures).

The product groups considered as priorities for such studies have been listed in the Working Plan 2012-2014 (established according article 16(1) of the Ecodesign Directive) and this list includes "windows". Therefore a preparatory study has been requested by the Commission.

This preparatory study is to be executed according the Methodology for the Ecodesign of Energy-related Products (MEErP, 2011)[1] which identifies eight (1+7) tasks and shall allow stakeholder involvement. This report is the final report of Task 4 or "Technology Analysis" of the study.

[1] http://www.meerp.eu/ VHK BV, Netherlands and COWI, Belgium: Methodology Study Ecodesign of Energy-related Products, MEErP Methodology Report, under specific contract SI2.581529, Technical Assistance for the update of the Methodology for the Ecodesign of Energy-using products (MEEuP), within the framework service contract TREN/R1/350-2008 Lot 3, Final Report: 28/11/2011

CHAPTER 2 INTRODUCTION

2.1. METHODOLOGY FOR ECODESIGN PREPARATORY STUDIES

This chapter introduces the objective of Task 4 of the full preparatory study. A full preparatory study follows the methodology for ecodesign of energy-related products established in 2011 (MEErP 2011) which itself is a succession of the former methodology dealing with energy-using products (MEEuP 2005) developed in 2005 to contribute to the creation of a methodology allowing evaluating whether and to which extent various energy-using products fulfil certain criteria according to Annex I and/or II of the Ecodesign Directive that make them eligible for implementing measures.

The full preparatory study is executed according seven tasks, as described below:

Task 1 – Scope (definitions, standards and legislation);

Task 2 – Markets (volumes and prices);

Task 3 – Users (product demand side);

Task 4 – Technologies (product supply side, includes both BAT and BNAT);

Task 5 – Environment & Economics (Base case LCA & LCC);

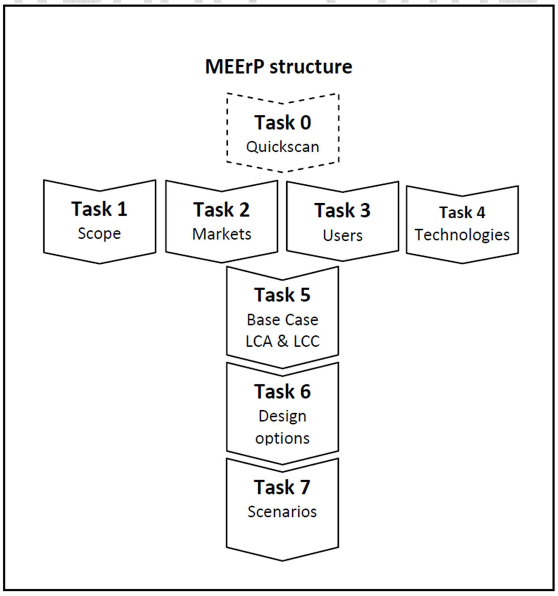
Task 6 – Design options;

Task 7 – Scenarios (Policy, scenario, impact and sensitivity analysis).

The MEErP structure makes a clear split between:

- Tasks 1 to 4 (product definitions, standards and legislation; economic and market analysis; consumer behaviour and local infrastructure; technical analysis) that have a clear focus on data retrieval and initial analysis;
- Tasks 5 (assessment of base case), 6 (improvement potential) and 7 (policy, scenario, impact and sensitivity analysis) with a clear focus on modelling.

Figure 1: MEErP structure



An optional Task 0 quick scan or first product screening has been introduced in the 2011 methodology for those product groups that are characterised by a large variety of products covered by a generic product group description. It was carried out for this study as well. The findings of this Task 0 are incorporated in the following Task 4 report.

Tasks 1 to 4 can be performed in parallel, whereas Task 5, 6 and 7 are sequential.

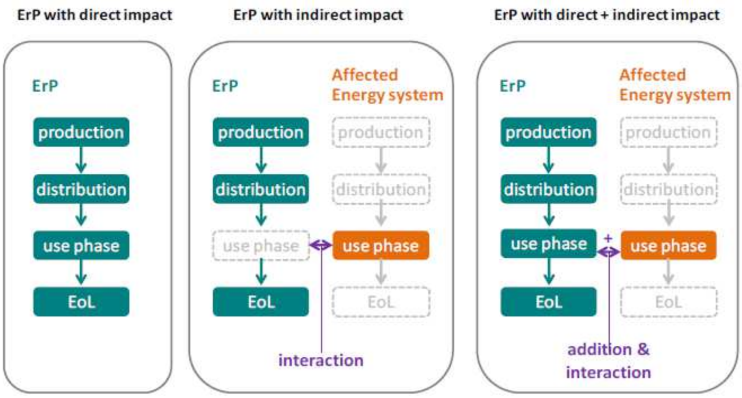
2.1.1. ENERGY RELATED PRODUCTS

The Directive 2009/125/EC defines an energy-related product as *"any good that has an impact on energy consumption during use which is placed on the market and/or put into service, and includes parts intended to be incorporated into* *energy-related products covered by this Directive, which are placed on the market and/or put into service as individual parts for end-users and of which the environmental performance can be assessed independently*".

The impact on energy consumption during use of an energy-related product may take different forms and the MEErP methodology defined these as either direct and/or indirect impacts. The relevance of this lies in the analysis required and which should or should not include affected energy systems.

The MEErP introduced a grouping of energy related products into products with only direct impacts, only indirect impacts or both.

Figure 2: Three types of ErP (VHK, 2011)



Considering the above indicated grouping in MEErP of ErP products windows are an example of ErP with indirect impact.

2.2. MEErP – Details of work for Task 4

Task 4 entails a general technical analysis of current products on the EU-market and provides general inputs for the definition of the Base case(s) (task 5) as well as the identification of the improvement potential (task 6).

As mentioned, the new Task 4 now incorporates the full range of technical reporting, from a description of the existing products up to BAT (Best Available Technology) and BNAT (Best Not yet Available Technology).

Figure 3: MEErP structure: Task 4 (from: MEErP Methodology Report Part1 (2011)

4 TECHNOLOGIES

Identify, retrieve and analyse data, report on

4.1 Technical product description, illustrated with data on performance, price, resources/emissions impact of

- 4.1.1 Existing products (working towards definition of BaseCases)
- 4.1.2 Products with standard improvement (design) options
- 4.1.3 Best Available Technology BAT (best of products on the market)
- 4.1.4 Best Not yet Available Technology BNAT (best of products in field tests, labs, etc.)

4.2 Production, distribution and end-of-life, specifically regarding

- 4.2.1 Product weight and Bills-of-Materials (BOMs), preferably in EcoReport format (see Task 5)
- 4.2.2 Assessment of the primary scrap production during sheet metal manufacturing
- 4.2.3 Packaging materials
- 4.2.4 Volume and weight of the packaged product
- 4.2.5 Actual means of transport employed in shipment of components, sub-assemblies and finished products[10]
- 4.2.6 Materials flow and collection effort at end-of-life (secondary waste), to landfill/ incineration/ recycling/ re-use (industry perspective)
- 4.2.7 Technical product life (time-to-failure of critical parts)

4.3 **Recommendations** for

- 4.3.1 refined product scope from the technical perspective (e.g. exclude special applications for niche markets)
- 4.3.2 barriers and opportunities for Ecodesign from a technical perspective
- 4.3.3 the typical design cycle for this product and thus approximately appropriate timing of measures

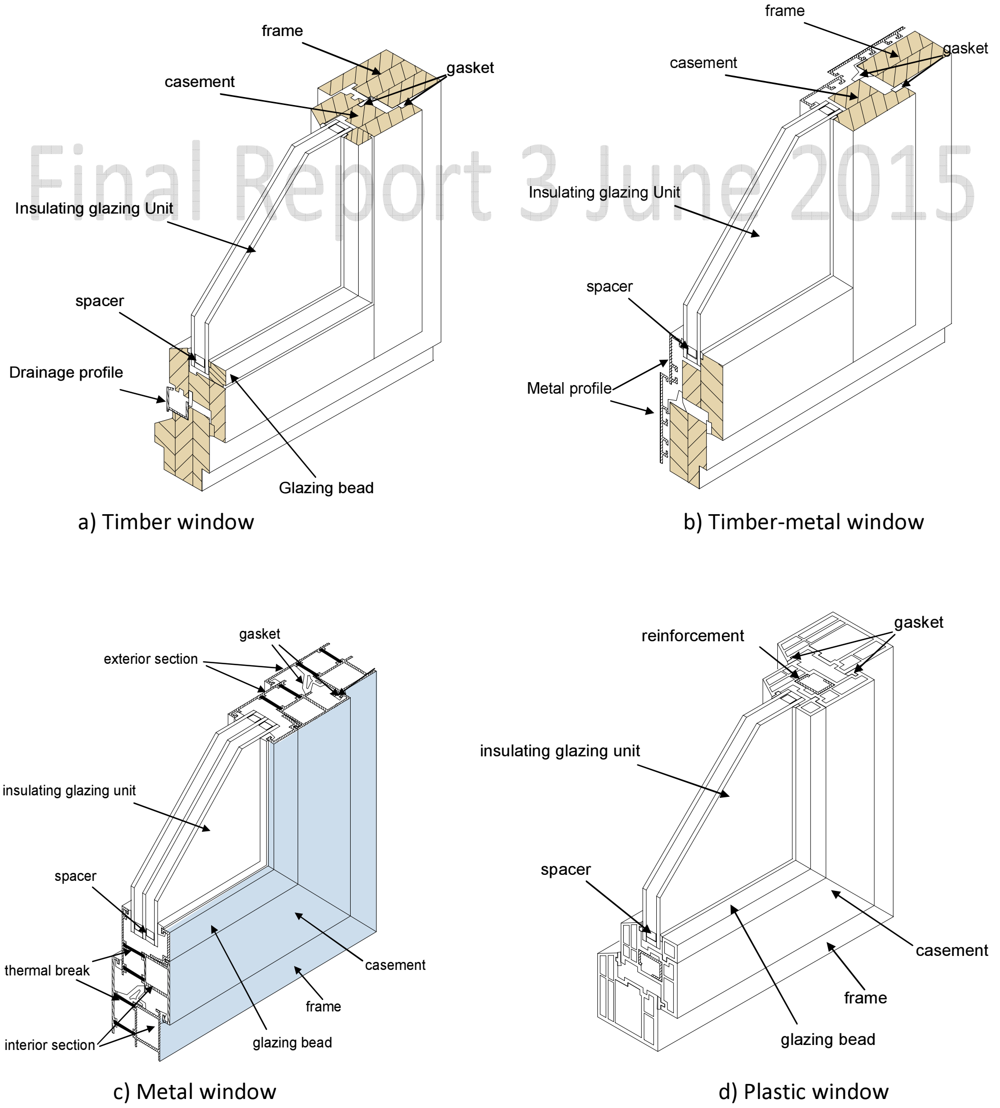
CHAPTER 3 TECHNICAL PRODUCT DESCRIPTION

The product group "windows" was identified as possible energy-related product in recital (4) of Directive 2009/125/EC (together with insulation materials and water-using products such as shower heads or taps).

Windows are generally understood as building components installed in the building envelope (e.g. wall, roof) that admit (day)light, solar heat and may also admit ventilation air to the spaces they (partly) enclose. Often they separate a climate conditioned indoor space from the unconditioned (outdoor) space, thus providing a thermal barrier that admits light, solar heat and possibly air. Windows offer a view to the outdoor environment, essential for the occupant's comfort.

Typically windows consist of a 'frame' and 'glazing'. If the glazing is fit into a moveable (operable) part, this part is called 'sash' (sliding windows) or casement (tilt and turn windows). Other components typical for windows are provisions to prevent air leakage (gaskets), to improve thermal performance (incorporating thermal insulation material, thermal breaks in metallic frames) or to improve durability (profiles for protection against weather) or for general construction purpose (glazing beads). Solar shading devices or shutters can be attached to the window. Typical schematic designs for inward opening windows (tilt and turn) are shown in Figure 4. It has to be noted, that the type of opening (inward/outward) depends on the region/country where the window is installed. Also the mechanism of opening e.g. sliding, tilt and turn etc. depends on the region/country.

Figure 4: Typical cross sections of windows by frame material



3.1. EXISTING PRODUCTS

This section covers both 'Existing products' as 'Products with standard improvement / design options' as required following the MEERP Methodology.

The window performance can be improved for each of the relevant aspects of the energy assessment, these being the overall U-value (determined by frame and glazing U-values, and psi-value of the spacer), the solar heat gain, the daylight transmittance and air leakage. The following sections describe options to improve this energetic performance.

3.1.1. THE OVERALL DESIGN

In the past, before the availability of IGU (with or without coating), often coupled and double windows were used. Due to the invention of IGUs it was no longer necessary to use coupled and double windows to achieve low thermal transmittance.

Single window

- One Frame/casement combination plus one transparent filling element (single glass, double IGU, triple IGU) for tilt and turn windows;
  One Frame and two sashes (at least one sliding); one transparent filling element in each sash (single glass, double IGU, triple IGU) for sliding windows (e.g. see also Figure 3-7);
- Shutter or blinds can be installed external or internal, and also IGU with integrated blind are possible, but expensive and not standard; For roof windows blinds or shutter must not be opened for the operation of the window
- Easy to clean (two surfaces instead of four as with coupled or double window).
- Roof windows have some form of IGU as standard
- can be fitted with automation which allows for controllability of natural ventilation and of shading devices

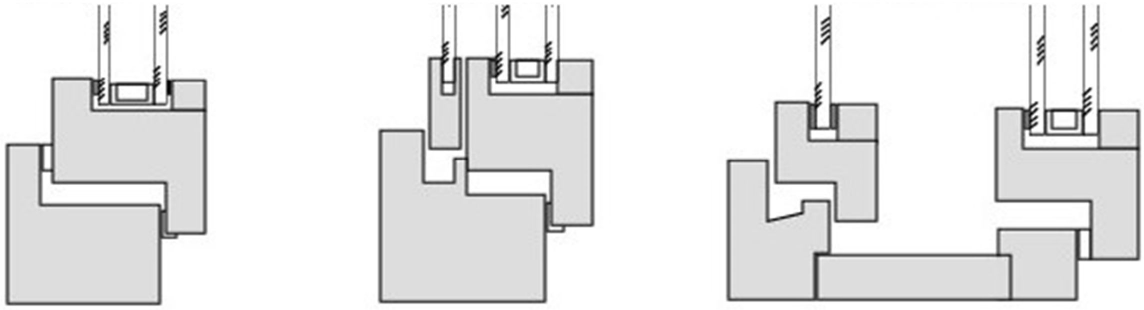
Coupled window

- One frame/two casements combination plus two transparent filling elements (single glass, double IGU, triple IGU), single glass normally installed in the outer sash, IGU normally installed in the inner sash; in principle it is also possible to have an IGU in the outer sash
- The casements are coupled (but operable), therefore the operation of the casement (opening, closing) is just as easy as for the single window;
- Shutter or blinds can be installed external or internal, but will normally be integrated between the sashes. The blind is protected from wind, rain and dirt, but can have similar performance than an exterior blind. Blind must not be opened for the operation of the window;
- can be fitted with automation which allows for controllability of natural ventilation and of shading devices
- Coupled windows allow also high sound insulations.
- *Coupled roof windows are available as a special product.*

Double window

- Two complete windows installed in series, separated by an cavity of approx. 100 mm;
- Several possibilities for the combination for the glass; Exterior: Single glass or double IGU, Interior: double or triple IGU,
- For the operation of the window (opening, closing) the two sashes have to be operated one after another;
- The additional cavity allows the integration of blinds/sun shading devices, but in most cases blinds must opened to open the window;
- Double windows allow very high sound insulations.

Figure 5: Construction of windows / sashes



From left to right:

- a) single window
- b) coupled window
- c) double window

Note: The shown types of glazing's can change, e.g. triple instead of double IGU or double IGU instead of single glass

Windows can be fitted with motors to allow power operated opening. Also sun shadings and shutters can be operated by means of motors.

3.1.2. Opening Types

For windows there are several types of opening. The following drawings, to describe common types of opening are taken from EN 12519.

Figure 6: fixed window

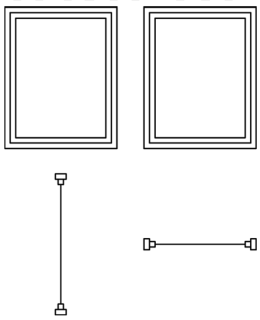


Figure 7: single side hung casement
left: opening inwards; right opening outwards

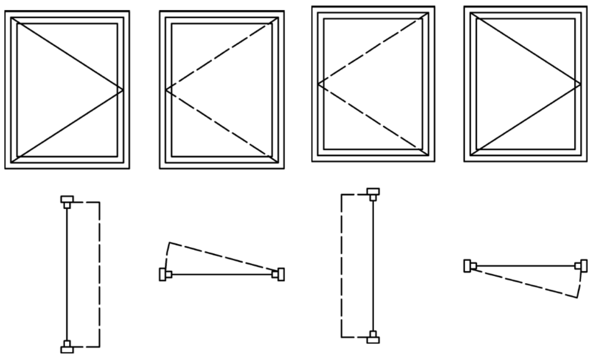


Figure 8: vertical pivot casement

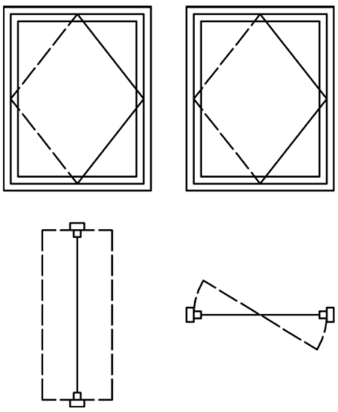


Figure 9: horizontal pivot casement

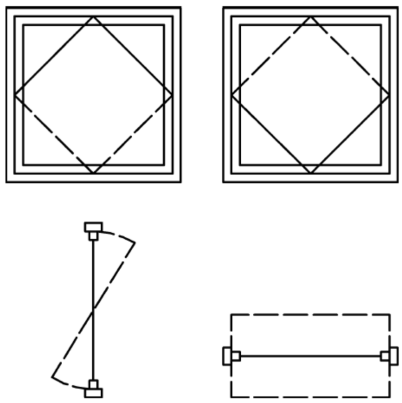


Figure 10: vertical sliding double sashes

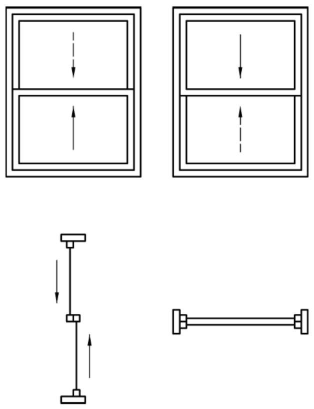


Figure 11: vertical sliding single bottom sash

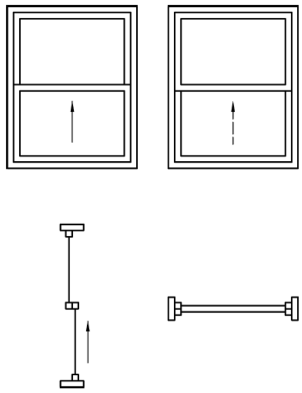


Figure 12: horizontal sliding single sash left

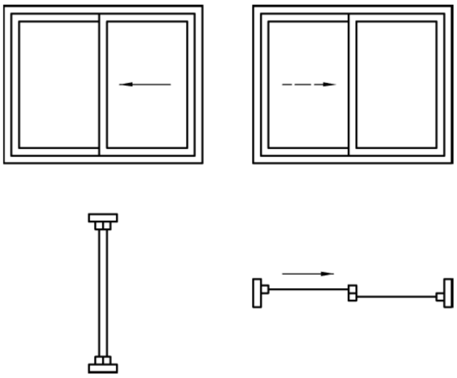


Figure 13: double horizontal sliding sash left sash along the front of the right sash

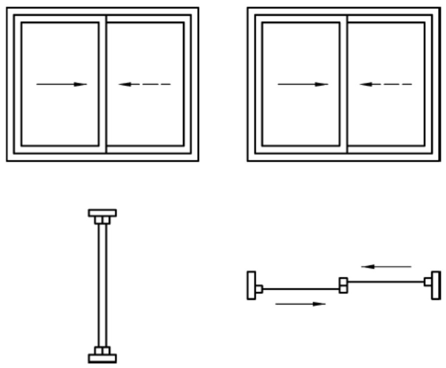


Figure 14: tilt and turn

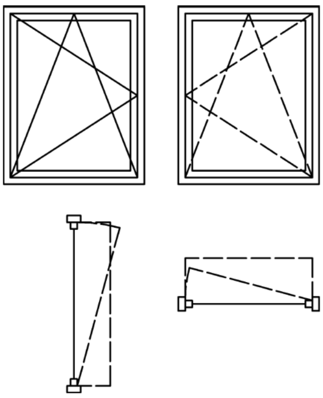


Figure 15: bottom hung casement

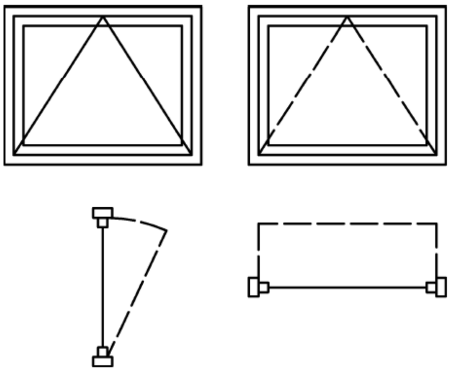
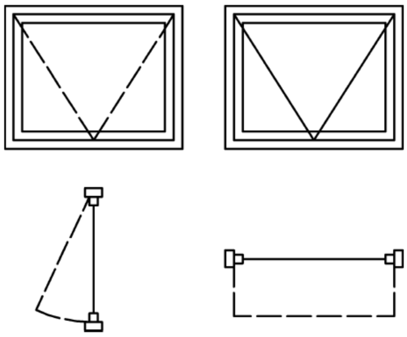


Figure 16: top hung casement outward opening



3.1.3. Frames

The following frame materials are used for windows in general:

- Metal (aluminium, steel; with or without thermal break)
- Timber (wood);
- Plastics (PVC).

The frames for roof windows are made of wood, PU or PVC. The exterior of the frame is metal-clad as a standard.

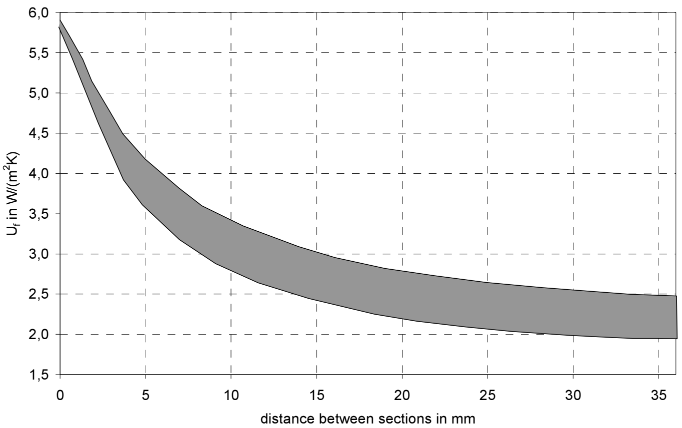
The energy related characteristic of the frame is the thermal transmittance U_f.

→ **Metal frames**

A metal (aluminium) frame with no thermal break has an $U_f \approx 6.0$ W/m^{2}K. By applying a thermal break this value can be reduced, but the thermal transmittance of the frame is influenced by different construction characteristics, such as:

- distance between the metal sections,
- width of the material of the thermal break zones,
- thermal conductivity of the thermal break material,
- ratio of the width of the thermal break to the projected frame width.

Figure 17: Indicative U_f-values of metal frames with thermal break[2]



By integrating thermal insulation materials in the thermal break zone or using the effect of reduced radiation exchange within the thermal break zone and also by enlarging the distance between the inner and outer section the U_f value of aluminium frames can be reduced significantly and U_f values down to 0.8-1.0 W/m^{2}K can be achieved.

[2] The diagram is based on Annex D of 10077-1.

→ **Timber frames**

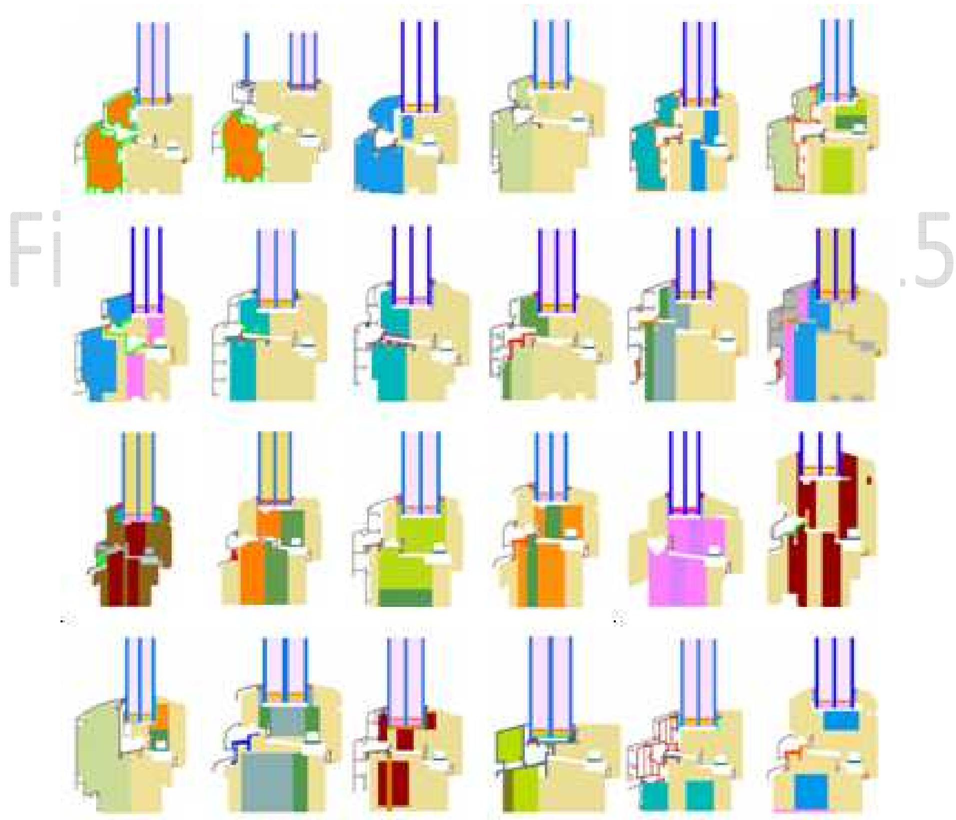
The main parameters influencing the U_f value of timber frames are the thickness of the frame and the thermal conductivity of the wood. Current frames have thicknesses between 60 and 90 mm. Different wood species have different thermal conductivities. EN ISO 10077-2 assigns thermal conductivities to different wood species. The thermal conductivity of soft wood is approx. 0.11 - 0.13 W/(m K), for hard wood 0.16 - 0.18 W/(m K).

Table 1: Thermal properties of timber frames

Thickness d in mm	Soft wood λ = 0.13 W/(m K)	Hard wood λ = 0.18 W/(m K)
50	$U_f \approx 1.7$ W/(m²K)	$U_f \approx 2.1$ W/(m²K)
70	$U_f \approx 1.5$W/(m²K)	$U_f \approx 1.9$ W/(m²K)
80	$U_f \approx 1.4$ W/(m²K)	$U_f \approx 1.8$ W/(m²K)
90	$U_f \approx 1.3$ W/(m²K)	$U_f \approx 1.7$ W/(m²K)

To achieve very low U_f-values for timber frames it is necessary to integrate thermal insulation products. Examples for timber frames with integrated thermal insulation are given in Figure 18.

Figure 18: Examples for timber frames with integrated thermal insulation[3]



The integration of thermal insulation material in the frame and the sash can be very complex. The easiest way is to integrate the insulation material only in the frame (see Figure 19). U_f values that can be achieved with such a solution are given in Figure 20. The values are based on the assumption, that a thermal insulation material with a thermal conductivity of λ = 0.25 W/(m K) is used

[3] The individual cross sections are taken from www.passiv.de

Figure 19: Scheme of a cross section with thermal insulation integrated in a timber frame

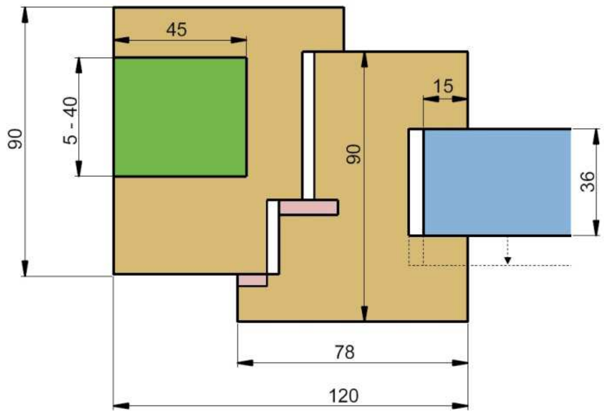
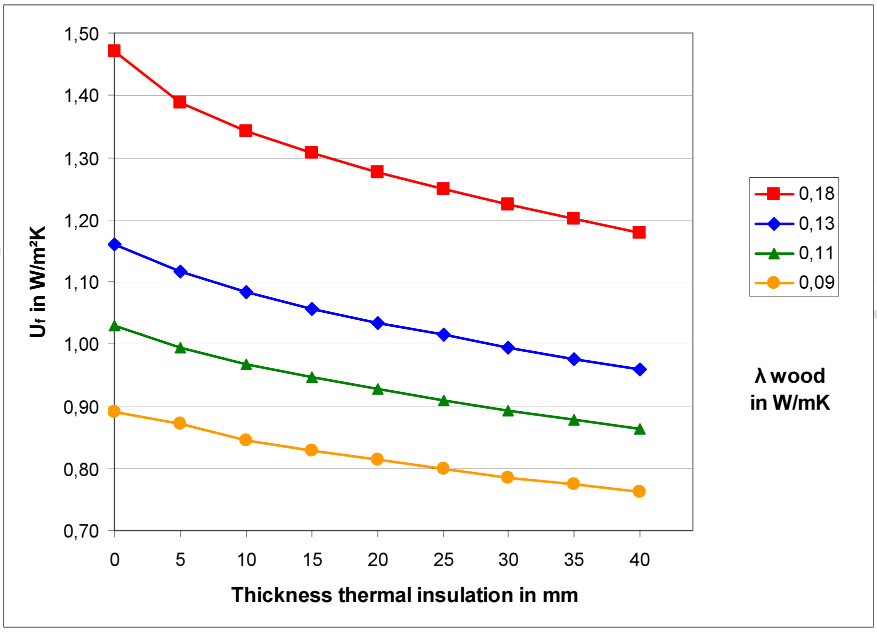


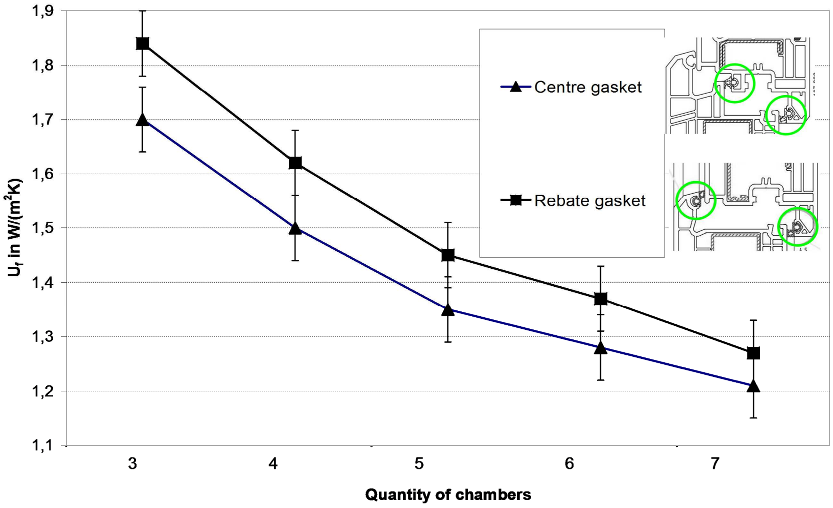
Figure 20: Typical U_f values of frames according to Figure 19



→ **Plastic frames**

The main parameter influencing the U_f value of plastic frames are the “quantity of chambers”. The quantity of chambers also influences the thickness of the profile. Furthermore the U_f-value depends on the design of the rebate between the frame and the sash; in particular of the “gasket system”.

Figure 21: Typical U_f-values of plastic frames



For a further reduction of the thermal transmittance of PVC profiles it is also possible and common to fill the chambers with thermal insulation material allowing to achieve U_f values in the range of U_f = 0.8 W/m^{2}K)

3.1.4. Transparent filling elements

→ **Glazing**

Transparent filling elements can be improved as regards their thermal transmittance (U-value), solar energy transmittance (g-value) and light transmittance (τ_v). Relevant energetic characteristics of typical transparent filling elements (glazing for heat insulation) are given in Table 2.

Table 2: Typical energy related characteristics of transparent filing elements

No.	Description	Typical cross section	Typical values		
			Thermal transmittance U_g in W/m^{2}K	Solar energy transmittance* g	Light transmittance* τ_v
1	Single glass	Float glass 4-8 mm Laminated glass 6-10 mm	5,9	≈ 0.85	≈ 0.90
2	Double glass units	Single panes: 4-8 mm Cavity width: 12-16 mm Low e coating: - Gas filling: Air	≈ 2,7	≈ 0.78	≈ 0.82
3	Double Insulating glass Units	Single panes: 4-8 mm Cavity width: 12-16 mm Low e coating: ε_n = 0.03- 0.05 Gas filling: Air, Argon	≈1.1 - 1.3	≈ 0.62	≈ 0.80
4	Triple Insulating glazing Units	Single panes: 4-8 mm Cavity width: 12-16 mm Low e coating: ε_n = 0.03- 0.05 Gas filling: Air, Argon	≈0.6- 0.7	≈0.55	≈ 0.70

*Stated values are for heat insulation glass. For solar control glass lower g values are available to reduce the solar gains and therefore the cooling load. (see also following text)

For the constructions No. 3 and 4 in the above table it has to be noted, that the stated values are typical for so called "heat insulation glazing". The primary goal of these heat protection glazing's is to decrease the thermal losses, meaning to reduce the U value and to increase the solar gains, by enhancing the g value. This strategy serves to reduce the heating demand of buildings.

To reduce the cooling demand of buildings so called solar control glass is a good possibility. In general solar control glass can have the same low U values as heat insulation glass. But the use of special coatings allows reducing simultaneously also the solar energy transmittance. As far as solar control glass is concerned there is no representative g value but a wide band of possible g values. So it is no problem to optimize the g-value according to the requirements for the special situation of the building. G-values in the range from 0.20 to 0.50 can be achieved easily. For solar control glass the coating is also optimized to allow a light transmittance as high as possible. The ratio of the light transmittance and the solar energy transmittance is called selectivity. With optimized coatings a selectivity of two can be achieved; resulting in a light transmittance that is twice as high as the g-value. For example for a g-value of 0.30 the light transmittance can be up to 0.60.

It has to be kept in mind, that solar control glass has static solar properties. Therefore also solar gains during the heating season are reduced. For that reason solar control glass is used especially for buildings where the cooling demand dominates.

Note: Although the light transmittance can be seen as an energy related characteristic the standards EN ISO 13790 and ISO 18292 do not give a method to calculated the impact of the light transmittance on the energy use for artificial lighting. See also TASK7; chapter about daylight potential.

Influence of the inclination on the thermal characteristic

According to the product standard for windows EN 14351-1 the declared thermal transmittance of windows and roof windows is evaluated in the vertical position. It has to be noted that the U_g value of an IGU (and therefore also the U_w value of a roof window) depends on the inclination. The effect of the inclination on the U_g value can be calculated according to EN 673. Figure 22 shows the U_g value of selected IGUs as a function of the inclination (90° is vertical; 0° is horizontal).

Figure 22: U_g calculated according to EN 673 as a function of the inclination for different designs of the IGU

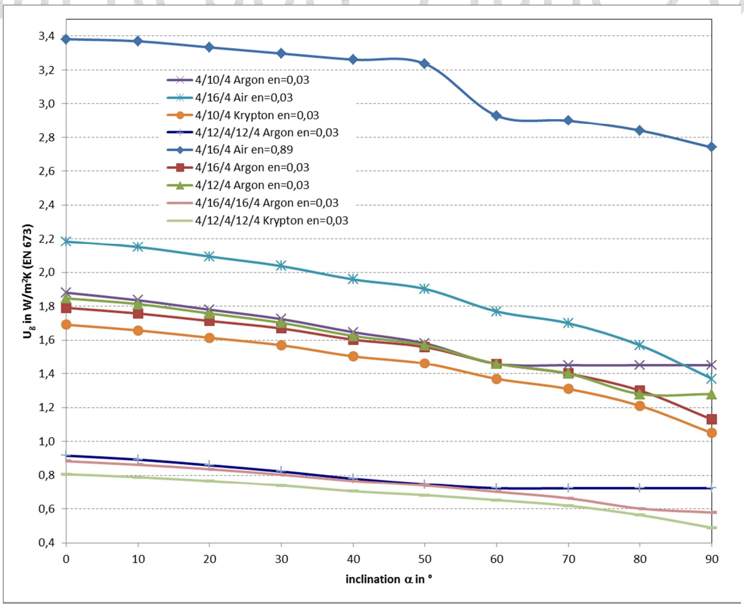
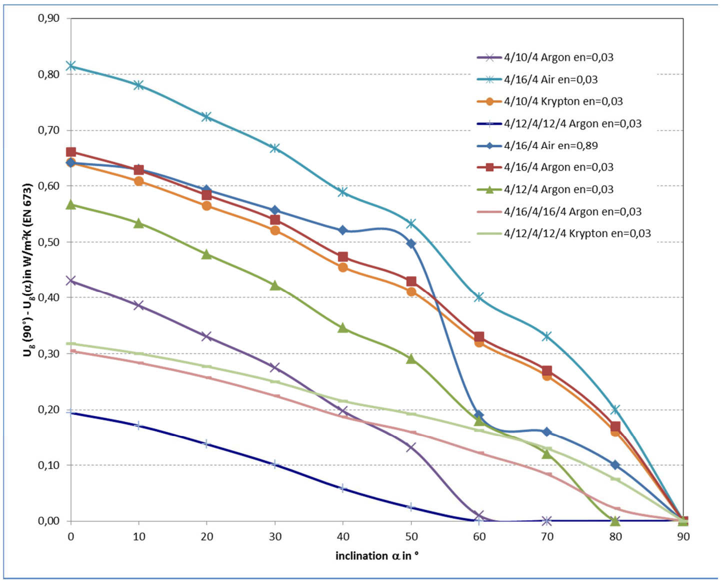


Figure 23 shows the ΔU_g value (U_g value with inclination minus U_g value for horizontal installation).

Figure 23: ΔU_g value as a function of the inclination



Note: According to ISO 6946 the internal surface resistance for horizontal heat flow (R_{si} = (0.13 m^2K)/W) apply to heat flow directions ±30° from the horizontal plane. As a consequence for inclinations greater than 30° the reduced internal surface resistance for heat flow upward (R_{si} = (0.10 m^2K)/W) has to be used for the calculation of U_g.

The calculations lead to the following conclusions:

- The inclination can have a significant effect on the Ug value and therefore on the Uw value of a roof window
- For IGUs with a cavity width optimized with respect to thermal transmittance for vertical installation ΔUg values can be derived (assuming a slope of 40°)
  Double IGU without low e: ΔUg ≈ 0,5 W/m^2K
  Double IGU with low e: ΔU_g ≈ 0,5W/m^2K
  Triple IGU with low e: ΔU_g = 0,2 W/m^2K
- For IGUs with reduced cavity width (and therefore higher U_g values for the vertical installation) the effect of inclination on the U_g value is reduced
- No positive effect in using triple glazing with an optimized cavity width of 16 mm in roof windows as far as thermal transmittance is concerned

According to EN ISO 10077-2 the effect of inclination should be considered in the calculation of the design U_W-value.:

Design values should be determined for the actual position and boundary conditions, by including the effect of the inclination of the window in the determination of U_g.[4]

A practical solution to transform the declared U_W value (CE marking) into a design value (used for the calculation of the energy balance) could be to add an additional thermal transmittance to the declared U_W-value:

$$U_{W,des} = U_W + \Delta U_W = U_W + F_F \cdot \Delta U_g$$

Glazings with dynamic optical properties also called switchable or smart glazings do exist by the use of laminated glazing's incorporating an electro chromic layer. The optical properties for a double IGU incorporating an electro chromic glazing as an external pane g-values from 0.15 to 0.40 and a light transmittance from 0.15-0.55 can be regulated with infinitely variable. To change the properties a low voltage supply is needed. „Switchable glazing" is not common and is a niche product (see also NBAT).

A different way to produce glazings with switchable optical properties is to integrate a sun shading device in the cavity of a double or triple IGU. Venetians blinds, fabrics or special films serve as the sun shading. The IGU itself is still hermetically sealed. Therefore the same thermal transmittances as for "normal" IGUs can be achieved. With the sun shading in up position, the optical properties of the system are identical to an IGU without integrated shading. With the sun shading in down position low g-values in the region of 0.10 to 0.15 can be achieved. Because of the fact that the sun shading device is integrated in a hermetically sealed unit it is not possible to get access to the device for maintenance or repair. In the

[4] EN ISO 10077-1; Chapter 6 Input values

case of a failure of the sun shading device the complete IGU has to be replaced. Therefore the proof a durability of such systems is essential. „Integrated shading in IGUs is not standard for windows and roof windows“.

For single glass, laminated glass, toughened glass and insulating glazing units there are harmonized European product standards.

- Single glass: EN 572-9 Glass in Building - Basic soda lime silicate glass - Part 9: Evaluation of conformity
- Laminated glass: EN 14449 Laminated glass and laminated safety glass Evaluation of conformity/Product standard
- Toughened glass: EN 12150-2 Thermally toughened soda lime silicate safety glass Part 2: Evaluation of conformity/Product standard
- Insulating glass units: EN 1279-5 Glass in Building - Insulating glass units - Part 5 - Evaluation of conformity

The relevant energy related characteristics are stated within the CE-mark of the glazing product.

→ **Spacer of the IGU**

The thermal transmittance of the insulated glazing unit (single or laminated glass without cavity does not require spacers), Ug, is applicable to the central area of the glazing and does not include the effect of the glass spacers at the edge of the glazing. On the other hand, the thermal transmittance of the frame, Uf, is applicable in the absence of the glazing. The linear thermal transmittance Ψ_g describes the additional heat conduction due to the interaction between frame, glazing and spacer, and is affected by the thermal properties of each of these components.

According to EN ISO 10077-1 there are in general two different types of spacers:

- Thermally not improved spacer(aluminium, steel)
- Thermally improved spacers or 'warm edge spacers' (stainless steel, polymeric materials)

EN ISO 10077-1 defines thermally improved spacers as follows:

$$\sum d \cdot \lambda \leq 0.007$$

The following tables are showing tabulated Ψ_g values for the two types of spacers

Table 3: Psi values for normal spacers [EN ISO 10077-1]

Frame type	Linear thermal transmittance for different types of glazing Ψ_g	
	Double or triple glazing uncoated glass air- or gas-filled	Double [a] or triple [b] glazing low-emissivity glass air- or gas-filled
Wood or PVC	0,06	0,08
Metal with a thermal break	0,08	0,11
Metal without a thermal break	0,02	0,05

[a] One pane coated for double glazed.
[b] Two panes coated for triple glazed.

Table 4: Psi values for thermally improved spacers [EN ISO 10077-1]

Frame type	Linear thermal transmittance for different types of glazing with improved thermal performance Ψ_g	
	Double or triple glazing uncoated glass air- or gas-filled	Double [a] or triple [b] glazing low emissivity glass air- or gas-filled
Wood or PVC	0,05	0,06
Metal with a thermal break	0,06	0,08
Metal without a thermal break	0,01	0,04

[a] One pane coated for double glazed.
[b] Two panes coated for triple glazed.

The linear thermal transmittance Ψ_g can also be calculated according to EN ISO 10077-2 in combination with the ift guideline WA-08/2 “Thermally improved spacers Part 1 Determination of representative Ψ-values for profile sections of windows”.

For most thermally improved spacer systems representative Ψ_g -values can be found in the data sheets of the Bundesverband Flachglas e.V.[5]

A thermally improved spacer can also reduce the risk of condensation at the interface between frame and glass.

3.1.5. Shutters and sun shading devices

Shutters and blinds can have a significant impact on the energetic performance of a window when properly used:

- When fully closed educe the thermal transmittance of the window by creating an additional cavity;
- When closed reduce the solar gains of the window by reflecting or absorbing the solar radiation, thus reducing a possible cooling demand (which could be met by artificial cooling).

Closed shutters and blinds may have an impact on the light transmittance of the window in combination with the shutter or blind. This can increase the need for artificial lighting.

The characteristic of the shutter/blind that has to be considered in the calculation of the thermal transmittance of the window U_W is the additional thermal resistance ΔR of the shutter/additional cavity between shutter and window. The thermal resistance can be evaluated according to EN ISO 10077-1 or EN 13125. When a shutter or a blind is in the extended position in front of a window, the U-value of the combination window + shutter/blind U_{WS} is given by the following formula:

$$U_{ws} = \frac{1}{\frac{1}{U_w} + \Delta R}$$

ΔR values are mainly a function of the solar shading/shutter material and air permeability.

[5] http://www.bundesverband-flachglas.de/shop/kostenfreie-downloads/bf-data-sheets-english/datenblaetter_engl.html

Table 5: ΔR-values for different shutter types [EN ISO 10077-1]

Shutter type	Typical thermal resistance of shutter R_{sh} m²·K/W	Additional thermal resistances at specific air permeability of the shutters [a] ΔR m²·K/W		
		High or very high air permeability	Average air permeability	Tight or low air permeability
Roller shutters of aluminium	0,01	0,09	0,12	0,15
Roller shutters of wood and plastic without foam filling	0,10	0,12	0,16	0,22
Roller shutters of plastic with foam filling	0,15	0,13	0,19	0,26
Shutters of wood, 25 mm to 30 mm thickness	0,20	0,14	0,22	0,30

[a] The definition of the air permeability of shutters is given in Annex H.

The g_{tot}-value is the characteristics taken into account for the evaluation of the solar gains of window with an additional shutter/blind. g_{tot} is the solar energy transmittance of the combination of the glass and the blind, g is the solar energy transmittance of the glass itself. The lower the g_{tot} value, the better is the "performance" of the sun shading device in combination with the glazing. g_{tot} can be evaluated according to EN 13363-1 or EN 13363-2. For the evaluation of g_{tot} the characteristics of the sun shading and also the glazing must be known.

External blinds have a significant better performance than internal blinds (see also Figure 24 and Figure 25).

A simplified approach for the characterisation of the shutter/sun shading is to use the so called shading coefficient F_C.

The Fc value is defined as follows:

$$F_c = \frac{g_{tot}}{g}$$

Figure 24 and Figure 25 are showing typical solar shading coefficients F_c for internal and external sun shading devices. The values were calculated according to EN 13363-1. The following boundary conditions were applied:

For Figure 24:

4 different glazings according to Table 2 were considered. The solar reflectance of the sun shading was varied from $\rho_{e,B} = 0.1$ to $\rho_{e,B} = 0.8$. The solar transmittance of the sun shading was assumed to be constant $\tau_{e,B} = 0.1$.

For Figure 25:

4 different glazings according to Table 2 were considered. The solar transmittance of the sun shading was varied from $\tau_{e,B} = 0$ to $\tau_{e,B} = 0.5$. The solar reflectance of the sun shading was assumed to be $\rho_{e,B} = 0.4$ for the non-transparent sun shading and $\rho_{e,B} = 0.2$ for the sun shading with a transmission of 0.5. All other values were linear interpolated.

Figure 24: Typical Solar shading coefficients for internal sun shading

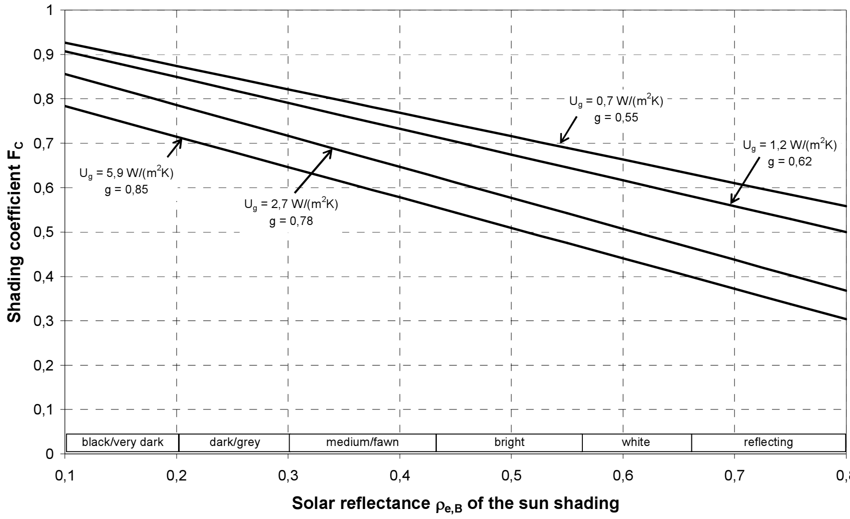
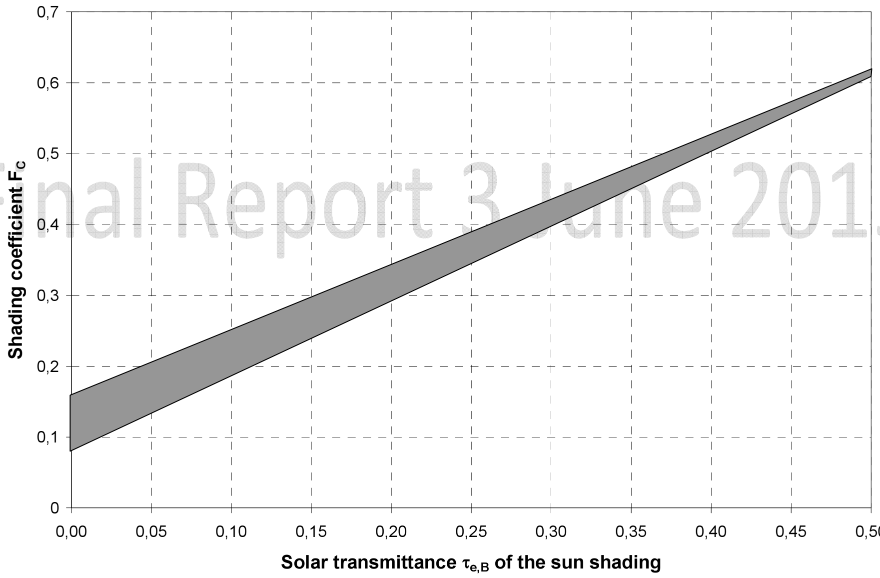


Figure 25: Typical Solar shading coefficients for external sun shading



One advantage of coupled windows is the possible integration of sun shading devices in the cavity between the two sashes. Because the two sashes are not fixed permanently and can be opened also during the use phase, it is very easy to get access to the sun shading for cleaning, maintenance or repair. The integration between the two sashes allows also to use “more simple” sun shading devices, because the device must not cope with the loads (wind, rain) if installed in an external position. The window itself can be operated as normal; it is possible to close or open the window also in the down position of the sun shading device. For roof windows coupled windows and integrated shading is not common.

In principle it is also possible to integrate a sun shading device in a double window. It must be noted, that for opening the window the sun shading device must be in the up position.

The performance of integrated sun shading devices depends very strong on the relation of the thermal resistances of layers to the internal environment to the thermal resistance of the layers to the external environment. For optimized systems it is possible to achieve nearly similar performance as for external sun shading devices.

For shutters and blinds there are the following harmonized European product standards:

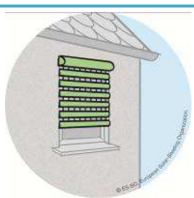
EN 13659 Shutters — Performance requirements including safety

EN 13561 External blinds — Performance requirements including safety

EN 13120 Internal blinds —Performance requirements including safety;

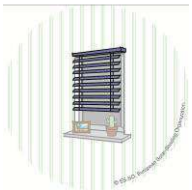
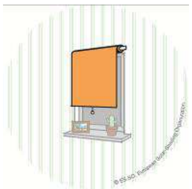
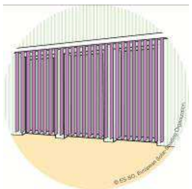
According to the relevant product standards for Shutters and External blinds the wind resistance is tested to show that the external system can be used under hard weather conditions.

Figure 26: Overview[6] of the main solar shading product types for exterior installation

Type	Picture	Description
External roller blind		Rolls down vertically along the window, solar shading agent is a fabric (most often fiberglass screen, polyester or acrylic), with head box for the protection of the fabric and side guide rails or cables for reliable performance
External Venetian blind		Horizontal aluminium slats can be raised or lowered, then adjusted to any angle to regulate the entrance of daylight. Head box and side rails or cables. Slat widths vary from 50 mm to 150 mm.
Drop-arm awning		'Drop-arm' or 'fall-arm' indicates an arm projecting forward when lowered. Equipped with a fabric and a head box for retracting the fabric.
Folding arm awning		Suitable for shop windows and patios, the folding arm awning is equipped with two or more folding arms, allowing to stretch the fabric (mostly acrylic) to extend up to 3 m or more. Often these awnings have closed cassettes to protect the fabric when retracted.
Sliding arm awning		Often referred to as 'marquisolette', this is a combination of the external vertical blind and the drop-arm awning, with the fabric dropping vertically, then projecting forward. Suits in particular high, narrow windows.
Conservatory awning		Designed to reduce the energy impact of the sun on all glass conservatories by externally covering the sloped roof and sometimes the front end of conservatories. Exists in various shapes and sizes. Equipped with solar shading fabric .
Roller shutter		Basically, a number of horizontal slats in aluminium or plastic, hinged together and rolling down or up. For windows, but also for doors, and even vans and trucks.

[6] Information submitted by European Solar Shading Organization

Figure 27: Overview[7] of the main solar shading product types for interior installation

Type	Picture	Description
Venetian blind		The quintessential interior blind, composed of slats of aluminium, wood or plastic that adjust by rotating from an open position to a closed position by allowing slats to overlap. Mostly operated with cord or wand, also available in motorized version. Slats can be perforated.
Roller blind		Rolls down vertically along the window on the inside or between the inner and outer wall of a double skin façade. Great variety of fabrics, including metallized fabrics for better reflection of the solar energy.
Vertical blind		System consisting of a number of vertical louvers, mostly made of fabric, more rarely of plastic or aluminium, moving to one side or to both sides. For large windows and sliding glass doors. Popular in the office environment.
Pleated blinds		Especially suitable for irregular window shapes, these blinds are equipped with a pleated fabric that rolls down the window. Very flexible, pleated blinds can be used for trapezoid or half-round window shapes, with a choice of control options.
Roman blinds		When lowered, these blinds (also named Roman shades) look like one flat panel, while opening them will bring the folds under one another. Exists in a great variety of fabrics, including darkening fabrics.

According to information submitted by ES-SO the total volume of shutters/sun shading in Europe is approx. 51.5 Mio Unis. 7.2 Mio Units or approx. 14% of the total volume of the above mentioned products are combined to windows during the manufacturing process and put on the market as a single product.

Figure 28: Overview[8] of shutters/sun shading combined with the window

Description	(picture)
Combined roller shutter	

[7] Information submitted by European Solar Shading Organization

[8] Information submitted by European Solar Shading Organization

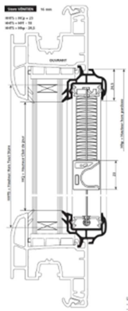
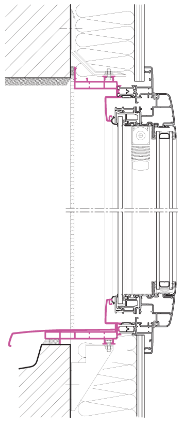
Description	(picture)
Combined external venetian blinds	 
Combined internal venetian and pleated blinds	 
Integrated venetian blinds	

Figure 29: Overview[9] of the main solar shading product types for roof windows - exterior installation

External roller shutter		Fits the roof window and does not prevent operation of the window even when rolled down. Panzer and side rails.
External awning blind		Fits the roof window and does not prevent operation of the window even when rolled down. Transparent cloth that ensures light in and view out.

Figure 30: Overview[10] of the main solar shading product types for roof windows - interior installation

Internal venetian blind		Horizontal slats, not loose handing cords and side rails that ensures perfect fit and smooth operation. You can operate the window even when the venetian blind is rolled down.
Internal blackout blind		Fits the window and side rails ensures perfect fit and total blackout. Handle bar for operation. You can operate the window even when the blackout blind is rolled down.
Internal pleated blind		Pleated blind that fits the window perfectly. Nice decorative pleats. Flexible position of the blind in the window. Handle bar in top and in bottom for easy and flexible operation. You can operate the window even when the pleated blind is rolled down.
Internal roller blind		Fits the window and side rails ensures perfect fit. Handle bar for operation. You can operate the window even when the roller blind is rolled down.

3.1.6. OPENING MECHANISMS

Opening mechanisms for windows (called “building hardware” in the standards) consist of

- hinges,
- locking elements and
- handles

which will often be connected to allow different ways to open (turn/tilt/abstay/slide etc. see also 3.1.2) and may be motorized and automated.

There may also be additional hardware for safety or comfort aspects. Safety elements may typically secure bottom-hung fanlights (i.e. a window element over a door) when released for cleaning purposes. A comfort element could be a sash brake preventing opened or bottom-hung window casements from slamming shut in a gust of wind.

[9] Information submitted by VELUX

[10] Information submitted by VELUX

Figure 31: Tilt and turn window hardware (Source: Winkhaus)

Figure 32: Further building hardware

Left: tilt and slide window hardware (Source: Gretsch Unitas)

Middle: Automated handle (Source Schüco)

Right: Automatic fanlight (Source: Gretsch Unitas)

Openable windows, or equipped with grilles for ventilation, can reduce building cooling loads by allow ventilative cooling (if outdoor air temperature < indoor air temperature), especially when automated (motorised).

3.2. Best Available Technologies

3.2.1. Definition of BEST AVAILABLE technology

In chapter 4.1.6 of the MEErP 2011 METHODOLOGY PART 1 FINAL report the following definition of Best Available Technology (BAT) is given:

The Best Available Technology benchmark should be a robust benchmark for market pull measures, e.g. the 'A' energy class and/or the level for public procurement, Eco-labels, etc..

The assessment of the BAT takes place on purely technical grounds, i.e. the product with the lowest environmental impact, but it should be clear that in terms of functional performance, quality and durability it should be a product that is at least equivalent to the Base Case. This is an important condition, because very often new products suffer from a subpar longevity and from subpar quality for certain aspects of their performance.

Therefore the best available technology (BAT) is defined as the combination of options where most energy savings can be reached irrespective of economic considerations.

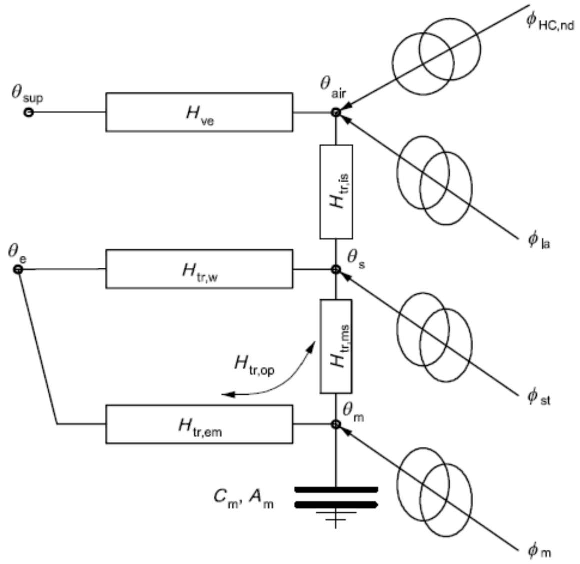
3.2.2. METHODOLOGY

The calculation procedure to determine the energy performance of windows is based on:

- ISO 18292 "Energy performance of fenestration systems for residential buildings — Calculation procedure" and
- EN ISO 13790 "Energy performance of buildings —Calculation of energy use for space heating and cooling".

The simple hourly dynamic calculation method according to EN ISO 13790 used for the study is able to model thermal transmission, heat flow by ventilation, thermal storage and internal and solar heat gains in the room. The model is based on an equivalent resistance-capacitance (R-C) model. It uses an hourly time step. Figure 33 shows the relevant RC network model.

Figure 33: RC network for the simple hourly method according to EN ISO 13790



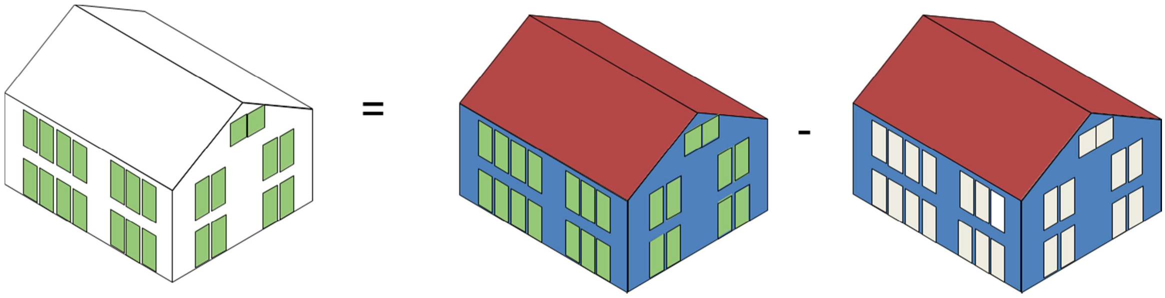
The heating and/or cooling need for the simulated building/zone is found by calculating for each hour the need for heating or cooling power, that needs to be supplied to, or extracted from, the room, to maintain a certain minimum or maximum set-point temperature.

Using the hourly calculation method, ISO 18292 does not give an explicit equation for the determination of the energy performance value of the window system but states that the annual heating and cooling energy associated with the fenestration system has to be calculated. This was achieved by the following approach.

To separate the energy demand associated to the window from the total energy demand of a building/room two calculations are performed

1. Calculation of the energy demand of the building/room with the "real window" installed
2. Calculation of the energy demand of the building/room with an "adiabatic window" ($U_W = 0$, $g_W=0$, no air leakage) installed

Figure 34 Visualisation of calculation procedure for window energy performance



The difference of these two calculations is the energy demand that can be associated to the window.

$$Q_{heat,window} = Q_{heat,room\ with\ real\ window} - Q_{heat,room\ with\ adibatic\ window}$$

$$Q_{cool,window} = Q_{cool,room\ with\ real\ window} - Q_{cool,room\ with\ adibatic\ window}$$

The calculated energy demand for heating $Q_{heat,window}$ in kWh/m2 and cooling $Q_{cool,window}$ in kWh/m2 is equivalent to the energy performance value. For this study this approach will be named "adiabatic approach".

This adiabatic approach was already used in the past by several scientific institutions to calculate the energy performance of windows. It was also recommended in a position paper ("Window Energy rating: a plea from the fenestration industry") published in June 2010 by the following stakeholders:

- European Aluminium Association
- European Solar Shading Organization
- Eurowindoor
- Glass for Europe

3.2.3. INVESTIGATED WINDOW DESIGN OPTIONS

According to ISO 18292 the energy related characteristics considered when calculating the energy performance index are:

- Thermal transmittance of the window;
- Solar energy transmittance of the window:;
- Air tightness of the window.

Note: According to ISO 18292 the light transmittance of the window is not considered in the calculation of the energy performance index. Instead, ISO 18292 defines a method for the calculation of the so called daylight potential of a window. ISO 18292 states that the daylight potential is an important parameter for fenestration system selection but is not used in the energy rating procedure. The daylight potential of the fenestration system should be quoted with the energy rating. Further details are given in TASK7.

With the existing technologies windows can be produced with a huge variety in the relevant energy related characteristics. As the properties of the window determine its performance (in a given context / boundary conditions) several window constructions have been defined on the basis of the applied available technologies.

To analyse the BAT the following 11 façade window configurations and 6 roof window configurations were defined. Of course many more configurations than the ones presented below exist, but the design options defined below (see also TASK 5) are considered to represent a good overview of available window types.

The energy performance of a window shall not only consider heating, but shall also consider a possible cooling demand. For that reason the influence of sun protection was investigated, too. Sun protection can be achieved by two means in general:

- The use of solar control glass;
- The use of sun shading devices.

To analyse the impact of solar control glass window constructions with a low g-value (and varying U_w values) have been added (façade window type 9-10-11, roof window type 6).

Calculations were performed for a situation with and without a shutter with the following energy related characteristics:

- Additional thermal resistance $\Delta R = 0.17\ m^2K/W$
- Solar shading coefficient $F_C = 0.1$

Façade windows

For façade windows 11 base cases have been assessed, representative of the range of facade windows available.

Table 6: Façade windows design options

No.	Thermal transmittance U_w in $W/(m^2K)$	Solar energy transmittance of the glazing g	Class Air tightness	Technical description of the window
1	5.8	0.85	2 ($27m^3/(h\ m^2)$ at 100 Pa)	Single glazing Frame: even no or bad thermal break
2	2.8	0.78	3 ($9m^3/(h\ m^2)$ at 100 Pa)	Double IGU Standard frame (wood, PVC, Metal)
3	1.7	0.65	4 ($3m^3/(h\ m^2)$ at 100 Pa)	Double IGU with low e-coating and argon filling Standard frame (wood, PVC, Metal)
4	1.3	0.60	4 ($3m^3/(h\ m^2)$ at 100 Pa)	Double IGU with optimized low e-coating and argon filling Standard frame (wood, PVC, Metal)
5	1.0	0.55	4 ($3m^3/(h\ m^2)$ at 100 Pa)	Triple IGU with low e-coating and argon filling Standard frame (wood, PVC, Metal)
6	0.8	0.60	4 ($3m^3/(h\ m^2)$ at 100 Pa)	Triple IGU with optimized low e-coating and argon filling, thermally improved spacer Improved frame (wood, PVC, Metal)
7	1.0	0.58	4 ($3m^3/(h\ m^2)$ at 100 Pa)	Single and Double IGU with low e-coating and argon filling, thermally improved spacer Coupled window(wood, PVC, Metal)
8	0.6	0.47	4 ($3m^3/(h\ m^2)$ at 100 Pa)	2 Double IGU with low e-coating and argon filling, thermally improved spacer Double window (wood, PVC, Metal)
9	2.8	0.35	3 ($9m^3/(h\ m^2)$ at 100 Pa)	Double IGU with solar control coating Standard frame (wood, PVC, Metal)
10	1.3	0.35	4 ($3m^3/(h\ m^2)$ at 100 Pa)	Double IGU with solar control coating (also low e) and argon filling Standard frame (wood, PVC, Metal)
11	0.8	0.35	4 ($3m^3/(h\ m^2)$ at 100 Pa)	Triple IGU with solar control coating (also low e) and argon filling, thermally improved spacer Improved frame (wood, PVC, Metal)

Roof windows

For roof windows 6 base cases have been assessed, representative of the range of roof windows available.

Table 7: Roof windows design options (incl. solar control glass)

No.	U_w in W/m²K	g	Description
1	5.8	0.85	Single glazing; Frame: metal-wood, no or bad thermal break
2	2.8	0.78	Double IGU; Standard frame (metal-wood or metal-PVC/PU, Metal)
3	1.3	0.60	Double IGU with Low-e coating and argon filling; Frame metal-PVC/PU or metal-wood
4	1.0	0.50	Triple IGU with Low-e coating and argon filling; thermally improved spacer; Frame metal-PVC/PU or metal-wood
5	0.8	0.50	Triple IGU with optimized Low-e coating and argon filling, thermally improved spacer; Frame metal-PVC/PU or metal-wood
6	1.3	0.35	Double IGU with Low-e coating and argon filling and solar control glazing; Standard frame metal-PVC/PU or metal-wood

3.2.4. BOUNDARY CONDITIONS FOR ASSESSMENT OF BAT

→ **Calculations based on a** 'single room'

One set of calculations are based on the 'single room' model.

To investigate the impact of different window systems on the energy demand for heating and cooling, the different window design options were "integrated" in the exterior wall of a single room (see Figure 35Figure 35). The exterior wall with the window is oriented to North, East, South and West to consider the effect of different window orientations.

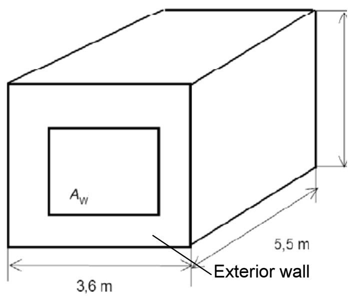
The advantages to base the calculations on a 'single room' model are the following:

- easy to separate façade and roof window effects (apply the solar radiation data for the relevant inclination for roof window)
- easy to separate orientation effects (apply the solar radiation data for the relevant orientation to the window)

The disadvantages/limitations to base the calculations on a 'single room' model are the following:

- the heat losses through the opaque building envelope are very low (especially in comparison to a single 'family house') is minimal as other walls are adiabatic (no roof and base plate considered). Therefore the utilisation factor for solar gains in winter is low (especially in comparison to a single family house). Solar gains lead much faster to a cooling need or overheating
- The single room approach may be more representative of apartment buildings as the exterior envelope is reduced.

Figure 35: Single room according to EN 13791; V = 55,4 m³; A_{floor} = 19,8 m²



This model implies that heating and cooling needs are not allocated over an entire building, but remain limited to the room. The utilisation rate may be smaller as overheating occurs more quickly. The main boundary conditions / assumptions are shown below (more details provided in Annex A):

Table 8: Boundary conditions and other parameters used for the calculation of the base case using the 'single room' approach

Parameter		Source
External Climate		
External Temperature T_e	Complete year, hourly data of T_e (Three different climates)	Meteo Norm Database
Solar Irradiance I_s	Complete year, hourly data of I_s for N;E;S;W (Three different climates)	Meteo Norm Database
Pressure Difference Δp	Δp=6 Pa	ISO 18292
Internal Climate		
Temperature set point for heating	T_i = 20°C	Table G.12 EN 13790
Temperature set point for cooling	T_i = 26°C	Table G.12 EN 13790
Room		
Dimensions	3,6 x 2,8 x 5,5 m^3	EN ISO 13791
Heat Capacity	heavy C^*_m = 260000 J/m^2K (A_{floor})	EN ISO 13790
U-value exterior wall	U_{wall}=0.8 W/m^2K	
Ventilation (General)	n=0.5 h^{-1}	
Increased Ventilation to allow ventilative cooling	n=2.0 h^{-1} for T_i>23°C and T_i>T_e	
Internal heat sources (related to floor area)	Q_i =5 W/m^2	DIN 4108-2 , see also Table G.8 EN 13790
Usage	24 h/7 days a week	
Window		
U_w value	Different values (see Table 6 and Table 7)	
g-value	Different values (see Table 6 and Table 7)	
Size	2,18 m x 1,48 m + 1,48 x 1,23 A_W = 5.05 m^2 (=>A_w/A_{floor} = 0,26)	
Frame fraction	FF=30%	
Infiltration	Different values (see Table 6 and Table 7)	EN 12207
Sun shading		
Fc-value	Fc = 1 and 0.1	
Set point for activation of the	I_s > 300 W/m^2	EN ISO 13790, Annex G:

sun shading	and T_e > 15°C	*Unless otherwise specified at national level, the solar shading shall be taken as being switched on if the intensity of the solar radiation on the surface at the given hour exceeds 300 W/m² and switched off if the hourly value is below this value.*
Additional ΔR **Note: Also applied when the sun shading is in active position during the day**	ΔR=0.17 m²K/W Sunset to sunrise complete year	EN 10077-1 Table G.1. Average air permeability Roller Shutter made out of wood or plastic

Additionally certain boundary conditions (e.g. window area/floor area, heat capacity, internal heat load) were varied to study the influence of these parameters on the result.

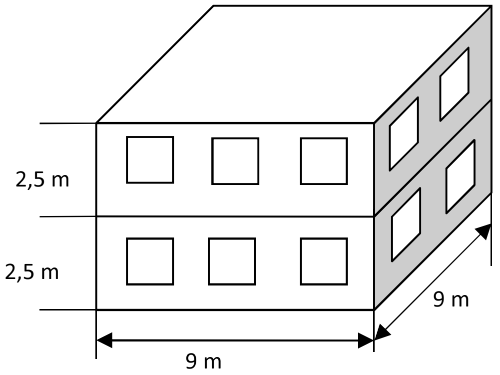
Table 9: Variations calculated for the 'single room' model

No.		Description
1	Base Case	Boundary conditions according to Table 8
2	Heat Capacity	As Base Case but with reduced heat capacity C^*_m = 165 000 J/m²K (A_{floor}) (medium according to EN 13790)
3	Window area	As Base Case but with reduced window area 2,18 m x 1,48 m A_W = 3.23 m² (=>A_W/A_{floor} = 0,16)
4	Natural ventilation	As Base Case but no increased ventilation for ventilative cooling
5	"Office building"	Reduced heat capacity C^*_m = 165 000 J/m²K (A_{floor}) Increased Window area: 10 m² (fully transparent façade) (=>A_W/A_{floor} = 0,65) Increased internal load by 50% (Q_i = 7,5W/m²) No openable elements => no ventilative cooling

→ **Calculations based on a 'single family house'**

On request by the Commission additional calculations were performed during the finalisation of the TASK 4 report to asses the BAT based on the 'single family house' approach that was also used in TASK7.

Figure 36 Simplified single family house; V = 405 m³; A_{floor} = 2x81 m²=162 m²



The orientation of the windows was assumed to be 25% on each facade. The ratio of the window area to the floor area was set to 20%.

The single family house was calculated by the approach of a "one-zone" model. In a one-zone model it is assumed, that there is only one representative air temperature; meaning that the temperature in different rooms is the same. Furthermore the "one-zone" model approach assumes that the solar gains achieved through a window will serve as an energy input for the complete building and not only for the room where the window is installed. The solar gains are distributed evenly; they are smoothed over the complete building. Therefore the so called utilization factor is the same for all windows.

The advantages to base the calculations on the single family house are:

- The heat losses through the opaque envelope are more realistic for a house. Therefore the utilisation of solar gains during winter will be higher.

The disadvantages/limitations to base the calculations on the single family house are:

- Not possible to separate façade and roof window effects when using the adiabatic approach;
- Not possible to separate orientation effects when using the adiabatic approach;
- A risk for under/overestimating OVERHEATING: As the single zone model assumes one representative air temperature for the whole zone (total house), the risk of possible overheating may be underestimated or overestimated when compared to a situation that surplus heat is not evenly distributed over the complete dwelling.

Table 10: Boundary conditions and other parameters used for the calculation of the base case using the single family house approach

Parameter		Source
External Climate		
External Temperature T_e	Complete year, hourly data of T_e (Three different climates)	Meteo Norm Database
Solar Irradiance I_s	Complete year, hourly data of I_s for N;E;S;W (Three different climates)	Meteo Norm Database
Pressure Difference Δp	Δp=6 Pa	ISO 18292
Internal Climate		
Temperature set point for heating	T_i = 20°C	Table G.12 EN 13790
Temperature set point for cooling	T_i = 26°C	Table G.12 EN 13790
Building		
Dimensions	9 x 9 x 5 m^3 => V = 405 m^3 ; A_{floor} =162 m^2	
Heat Capacity	heavy C^*_m = 260 000 J/m^2K (A_{floor})	EN ISO 13790
U-value opaque envelope	See Table 11	
Ventilation (General)	n=0.5 h^{-1}	
Increased Ventilation to allow ventilative cooling	n=2.0 h^{-1} for Ti>23°C and Ti>Te	
Internal heat sources (related to floor area)	Q_i =5 W/m^2	DIN 4108-2 , see also Table G.8 EN 13790

Usage	24 h/7 days a week	
Window		
U_w value	Different values (see Table 6 and Table 7)	
g-value	Different values (see Table 6 and Table 7)	
Ratio window area to floor area	Aw/Afloor = 0,20	
Frame fraction	FF=30%	
Infiltration	Different values (see Table 6 and Table 7)	EN 12207
Sun shading		
Fc-value		
Set point for activation of the sun shading	I_s > 300 W/m^2 and T_e > 15°C	EN ISO 13790, Annex G: *Unless otherwise specified at national level, the solar shading shall be taken as being switched on if the intensity of the solar radiation on the surface at the given hour exceeds 300 W/m^2 and switched off if the hourly value is below this value.*
Additional ΔR **Note: Also applied when the sun shading is in active position during the day**	ΔR=0.17 m^{2}K/W Sunset to sunrise complete year	EN 10077-1 Table G.1. Average air permeability Roller Shutter made out of wood or plastic

Different levels of insulation of the opaque envelope were investigated.

Table 11 Level of thermal insulation of the single family house

Climate		Mean U-value of the opaque building envelope $\tilde{U}_{env}$ in W/m^{2}K
North	Single family house "old"	0,6
	Single family house "renovated"	0,3
Central	Single family house "old"	0,8
	Single family house "renovated"	0,4
South	Single family house "old"	1,0
	Single family house "renovated"	0,6

→ **Calculations for three different climate conditions**

The calculations have been performed for three different climate conditions. These conditions determine the outdoor temperatures and the solar irradiance applicable to the window.

The three conditions were selected on the basis of the following grounds: One condition should be representative of the EU average climate. In the preparatory study for room air conditioners (see reports produced under DG ENER Lot 10, Ecodesign studies for room air conditioners by Armines, France) it was shown that Strasbourg can be considered representative of the average EU climate.

Then two much more extreme conditions were selected to show the sensitivity of the calculations for a heating dominated climate and a cooling dominated climate. For the heating dominated climate the city of Helsinki was selected, and for the cooling dominated climate the city of Athens, also consistent to the Lot 10 study. Nonetheless, these three locations show a good spread in outdoor temperatures and solar irradiance.

By doing so, the selection of climate conditions is consistent with the methodology required to be applied to the study (MEErP 2011, part 2, Section 6.2 Climate, Table 25: heating seasons, and Table 27: solar irradiance).

More notes on the selection of climate conditions (for window labelling) are included in the TASK 7 report.

3.2.5. BAT FOR HEATING AND COOLING PERFORMANCE OF FAÇADE WINDOWS IN RESIDENTIAL BUILDINGS BASED ON THE SINGLE ROOM

The table below shows the results of the calculation for façade windows in both heating and cooling situations and for use without (No. 'a') and with (No. 'b') shutters. The calculation is based on the single room model. The results given are calculated for an average orientation assuming 25% in each direction (North, East, West and South).

Table 12 Calculation energy performance of façade windows, with/without shutters, single room

No.	U_w in $W/(m^2K)$	g	Airtightness class	Energy use in $kWh/(m^2\ a)$ related to m^2 window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	600.8	18.7	619.5	365.0	36.6	401.6	75.9	211.1	287.0
2a	2.8	0.78	3	222.3	28.5	250.8	122.4	48.4	170.9	9.2	212.1	221.3
3a	1.7	0.65	4	99.8	23.6	123.4	49.2	41.3	90.4	-3.0	178.7	175.6
4a	1.3	0.60	4	67.2	21.1	88.2	30.1	37.6	67.7	-5.5	164.9	159.3
5a	1.0	0.55	4	43.8	18.1	61.8	16.7	33.3	50.0	-7.1	150.2	143.1
6a	0.8	0.60	4	21.1	24.0	45.0	2.3	41.4	43.6	-9.2	169.2	160.1
7a	1.0	0.58	4	41.0	20.8	61.8	14.6	37.1	51.8	-7.5	160.5	152.9
8a	0.6	0.47	4	13.7	13.2	26.9	0.0	26.3	26.3	-8.8	126.3	117.5
9a	2.8	0.35	3	282.5	3.1	285.6	170.8	9.4	180.2	33.8	85.8	119.6
10a	1.3	0.35	4	95.7	4.8	100.4	51.7	12.7	64.4	1.2	87.5	88.6
11a	0.8	0.35	4	45.8	5.5	51.2	21.1	14.0	35.1	-4.7	88.7	84.0
with shutter												
1b	5.8	0.85	2	434.8	1.0	435.8	266.7	10.7	277.4	45.8	88.1	134.0
2b	2.8	0.78	3	165.9	1.7	167.6	90.0	14.6	104.6	3.3	77.7	81.0
3b	1.7	0.65	4	76.0	1.3	77.4	35.7	12.2	47.9	-4.9	63.8	58.8
4b	1.3	0.60	4	52.5	1.2	53.7	21.8	11.1	33.0	-6.6	58.6	52.0
5b	1.0	0.55	4	34.8	1.0	35.8	11.8	9.9	21.7	-7.7	53.4	45.7
6b	0.8	0.60	4	15.2	1.4	16.6	-0.9	12.2	11.3	-9.5	58.7	49.2
7b	1.0	0.58	4	32.1	1.2	33.3	9.6	11.0	20.6	-8.1	56.5	48.4
8b	0.6	0.47	4	10.3	0.7	11.0	-1.8	8.0	6.1	-9.0	45.0	36.1
9b	2.8	0.35	3	224.6	0.2	224.8	137.8	3.7	141.5	25.7	37.3	63.0
10b	1.3	0.35	4	80.7	0.3	81.0	43.9	4.4	48.3	0.0	33.8	33.9
11b	0.8	0.35	4	39.8	0.4	40.1	18.1	4.7	22.9	-5.0	33.2	28.2

The lowest energy consumption (highest overall –combined- energy performance) is achieved by windows with a movable shading device (shutter) as they benefit from reduced Uw values and reduced demand for cooling (type 6b and 8b) except for the South climate condition[11]. When looking at heating and cooling separately the lowest cooling demands are achieved by windows with solar control glazing and/or windows with movable shutters and the lowest heating demands are achieved by windows with low U_w values.

[11] The 'combined values' simply sum the performance for heating and cooling and do not consider whether artificial cooling is indeed applied, nor the possible differences in energy system efficiencies and unit costs.

→ **Sensitivity analysis**

The effect of varying boundary conditions (reduced heat capacity, reduced window area, no ventilative cooling, separate orientations) are presented in Annex B and this shows that the sensitivity as regards 'heat capacity' and 'reduced window area' (ratio from 26% to 16%) is limited.

When considering 'no ventilative cooling' it shows that the single glazing option (type 1a/b) in a cooling situation is improved when compared to the reference. The reason may be that this window allows easier heat loss from inside to outside when outdoor temperatures are lower than inside. This is in many cases not considered a representative situation, but does show the influence of changing boundary conditions.

Non-residential buildings

Boundary conditions more representative of non-residential buildings can differ significantly in the relevant parameters (e.g. ratio of the window area to floor area; internal loads, usage etc.). This is expected to have a significant impact on the energy performance of the investigated design options and on the ranking. Therefore it is not possible (or at least very hard) to define a representative BAT for non-residential buildings. identification of the BAT or best solution for such buildings has to be answered by the assessment based on an holistic approach, considering all the relevant parameters of the building.

→ **BAT Façade windows, single room approach**

The calculations based on the single room show that the best (lowest total energy consumption, without consideration of costs) available technology for façade windows, assuming reference boundary conditions, is:

A) with a shutter/sun shading:

1. for Climate North and Central: Openable window with very low U-value and high g-value, moveable external shutter
2. for Climate South: Openable window with low U-value and low g-value, moveable external shutter/sun shading device

B) without a shutter/sun shading:

1. for Climate North and Central: Openable window with very low U-value and high g-value
2. for Climate South: Openable window with low U-value and low g-value

3.2.6. BAT FOR HEATING AND COOLING PERFORMANCE OF ROOF WINDOWS IN RESIDENTIAL BUILDINGS BASED ON THE SINGLE ROOM

The table below shows the results of the calculation for **roof windows** in both heating and cooling situations and for use without (No. 'a') and with (No. 'b') shutters. The results given are calculated for an average orientation assuming 25% in each direction (North, East, West and South) and a representative inclination of 40°.

Table 13 Calculation energy performance of roof windows, with/without shutters, single room

No.	U_w (W/m^2K)	g	Airtightness class	Energy use in kWh/(m^2 a)related to m^2 window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	571.1	47.4	618.6	331.3	96.3	427.5	57.6	407.7	465.3
2a	2.8	0.78	3	205.8	67.1	272.9	102.4	122.3	224.7	3.5	419.7	423.2
3a	1.3	0.60	4	57.9	50.2	108.1	17.5	94.8	112.3	-7.7	328.3	320.7
4a	1.0	0.50	4	40.3	34.8	75.1	9.7	70.3	80.0	-8.1	265.9	257.8
5a	0.8	0.50	4	22.2	36.4	58.5	-1.0	72.8	71.8	-9.3	268.8	259.4
6a	1.3	0.35	4	86.2	12.8	99.0	41.5	32.9	74.4	-2.2	170.8	168.6
with shutter												
1b	5.8	0.85	2	404.7	1.2	405.9	233.9	9.3	243.1	35.4	67.6	103.0
2b	2.8	0.78	3	153.0	2.4	155.4	72.2	10.9	83.1	-1.0	59.6	58.6
3b	1.3	0.60	4	44.2	1.4	45.6	9.9	8.5	18.3	-8.5	44.6	36.2
4b	1.0	0.50	4	31.8	0.7	32.5	5.0	6.5	11.5	-8.6	36.7	28.1
5b	0.8	0.50	4	16.6	0.8	17.4	-4.1	6.7	2.7	-9.6	36.6	27.0
6b	1.3	0.35	4	72.0	0.2	72.2	34.2	3.6	37.8	-3.0	26.2	23.2

BAT Roof windows, single room approach

The calculations based on the single room calculation applied to roof windows, shows that the best performance (lowest combined energy consumption, without consideration of costs) for roof windows is:

A) with a shutter/sun shading:

1. for Climate North: Openable window with very low U-value and high g-value, moveable external shutter
2. for Climate Central: Openable window with very low U-value and high to moderate g-value, moveable external shutter
3. for condition South: Openable window with low U-value and low g-value, moveable external shutter/sun shading device.

B) without a shutter/sun shading:

1. for condition North: Openable window with very low U-value and high g-value, moveable external shutter
2. for condition Central: Openable window with very low U-value and high to moderate g-value, moveable external shutter
3. for condition South: Openable window with low U-value and low g-value, moveable external shutter/sun shading device.

3.2.7. BAT FOR HEATING AND COOLING PERFORMANCE OF FAÇADE WINDOWS IN RESIDENTIAL BUILDINGS BASED ON THE SINGLE FAMILY HOUSE

The tables below show the results of the calculation for **facade windows** in both heating and cooling situations and for use without (No. 'a') and with (No. 'b') shutters. The calculation is based on the single family house. The tables are showing the calculated energy performance for the two different insulation levels of the opaque thermal envelope. Furthermore the tables show the result without and with ventilative cooling during the cooling period.

For facade windows without ventilative cooling, and high Uenv values (older homes).

Table 14 Calculation energy performance of façade windows, with/without shutters single family house, U_{env}=0,6 W/(m^2K) Climate North; U_{env}=0,8 W/(m^2K) Climate Central; U_{env}=1,0 W/(m^2K) Climate South, no ventilative cooling

No.	U_w in W/(m^2K)	g	Airtightness class	Energy use in kWh/(m^2 a)related to m^2 window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	546.2	14.3	560.5	316.0	27.1	343.1	35.4	180.6	216.0
2a	2.8	0.78	3	170.0	25.5	195.5	72.4	37.0	109.4	-53.6	174.0	120.3
3a	1.7	0.65	4	51.2	22.7	73.9	0.5	32.0	32.5	-70.5	145.5	75.0
4a	1.3	0.60	4	21.0	20.7	41.7	-16.8	29.3	12.5	-73.0	134.1	61.2
5a	1.0	0.55	4	0.5	18.1	18.6	-27.8	26.1	-1.7	-72.9	122.4	49.4
6a	0.8	0.60	4	-28.2	24.2	-4.1	-48.4	32.2	-16.2	-84.8	136.1	51.3
7a	1.0	0.58	4	-4.9	20.8	15.9	-32.6	29.0	-3.6	-77.3	130.1	52.8
8a	0.6	0.47	4	-24.4	13.8	-10.6	-40.3	20.8	-19.6	-70.6	103.2	32.6
9a	2.8	0.35	3	253.6	2.5	256.1	146.4	7.7	154.1	15.6	73.1	88.7
10a	1.3	0.35	4	68.8	4.9	73.7	25.9	10.3	36.2	-32.6	73.1	40.5
11a	0.8	0.35	4	18.8	6.0	24.8	-6.5	11.4	5.0	-45.5	73.6	28.1
with shutter												
1b	5.8	0.85	2	384.3	1.4	385.7	226.2	11.4	237.6	24.5	78.9	103.4
2b	2.8	0.78	3	119.7	2.4	122.1	54.1	13.3	67.4	-39.7	68.0	28.3
3b	1.7	0.65	4	31.9	2.2	34.2	0.2	11.5	11.7	-52.0	55.2	3.2
4b	1.3	0.60	4	10.6	2.1	12.7	-12.0	10.6	-1.5	-53.3	50.6	-2.7
5b	1.0	0.55	4	-4.4	1.8	-2.6	-20.1	9.6	-10.6	-52.8	46.0	-6.8
6b	0.8	0.60	4	-30.2	2.5	-27.7	-38.6	11.4	-27.2	-63.9	50.3	-13.6
7b	1.0	0.58	4	-9.9	2.1	-7.7	-24.7	10.4	-14.3	-56.9	48.6	-8.2
8b	0.6	0.47	4	-23.9	1.4	-22.5	-30.1	8.0	-22.1	-50.7	38.7	-12.0
9b	2.8	0.35	3	204.2	0.3	204.6	121.9	3.8	125.7	20.1	33.0	53.1
10b	1.3	0.35	4	58.9	0.6	59.5	27.7	4.7	32.3	-17.8	29.6	11.7
11b	0.8	0.35	4	17.3	0.7	17.9	0.7	5.0	5.8	-28.7	28.8	0.2

And for facade windows with ventilative cooling, and high Uenv values (older homes).

Table 15 Calculation energy performance of façade windows, with/without shutters single family house, U_{env}=0,6 W/(m^2K) Climate North; U_{env}=0,8 W/(m^2K) Climate Central; U_{env}=1,0 W/(m^2K) Climate South, ventilative cooling

No.	U_w in W/(m^2K)	g	Airtightness class	Energy use in kWh/(m^2 a)related to m^2 window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	546.8	7.3	554.1	316.6	19.4	336.0	35.8	167.9	203.7
2a	2.8	0.78	3	170.3	9.3	179.6	72.8	21.0	93.8	-53.2	153.8	100.6
3a	1.7	0.65	4	51.6	6.9	58.4	0.7	16.1	16.8	-70.3	125.5	55.2
4a	1.3	0.60	4	21.4	5.8	27.2	-16.7	14.3	-2.4	-72.8	114.8	42.1
5a	1.0	0.55	4	0.8	4.9	5.7	-27.8	12.3	-15.4	-72.7	104.1	31.3
6a	0.8	0.60	4	-27.9	6.4	-21.5	-48.2	15.0	-33.3	-84.6	115.2	30.5
7a	1.0	0.58	4	-4.6	5.6	1.1	-32.5	13.7	-18.8	-77.1	110.6	33.5
8a	0.6	0.47	4	-24.1	3.4	-20.7	-40.3	9.4	-30.9	-70.4	86.9	16.5
9a	2.8	0.35	3	253.9	1.0	254.9	146.4	4.5	151.0	15.6	66.8	82.5
10a	1.3	0.35	4	69.1	1.3	70.4	25.9	5.1	30.9	-32.6	63.4	30.8
11a	0.8	0.35	4	19.2	1.5	20.6	-6.5	5.2	-1.3	-45.4	62.7	17.3
with shutter												
1b	5.8	0.85	2	384.4	0.7	385.1	226.3	8.2	234.5	24.5	74.7	99.2
2b	2.8	0.78	3	119.8	0.7	120.6	54.1	7.9	62.0	-39.6	61.1	21.5
3b	1.7	0.65	4	32.0	0.5	32.6	0.2	6.3	6.4	-52.0	48.4	-3.6
4b	1.3	0.60	4	10.7	0.5	11.2	-12.1	5.7	-6.4	-53.2	44.0	-9.3
5b	1.0	0.55	4	-4.3	0.4	-3.9	-20.2	5.0	-15.2	-52.8	39.7	-13.1
6b	0.8	0.60	4	-30.1	0.5	-29.6	-38.7	5.8	-32.9	-63.9	43.0	-20.9
7b	1.0	0.58	4	-9.8	0.4	-9.3	-24.8	5.5	-19.3	-56.9	41.9	-14.9
8b	0.6	0.47	4	-23.9	0.3	-23.6	-30.2	4.1	-26.1	-50.6	33.1	-17.5
9b	2.8	0.35	3	204.3	0.1	204.4	121.9	2.5	124.4	20.1	31.4	51.5
10b	1.3	0.35	4	58.9	0.1	59.0	27.6	2.6	30.2	-17.8	26.5	8.7
11b	0.8	0.35	4	17.3	0.1	17.5	0.7	2.7	3.3	-28.7	25.3	-3.4

For facade windows without ventilative cooling, and low Uenv values (modern homes).

Table 16 Calculation energy performance of façade windows, with/without shutters single family house, U_{env}=0,3 W/(m²K) Climate North; U_{env}=0,4 W/(m²K) Climate Central; U_{env}=0,6 W/(m²K) Climate South, no ventilative cooling

No.	U_w in W/(m²K)	g	Airtightness class	Energy use in kWh/(m² a)related to m² window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	580.9	23.5	604.4	343.1	39.4	382.5	48.0	200.6	248.6
2a	2.8	0.78	3	196.7	48.8	245.5	95.4	63.5	158.9	-36.3	201.5	165.2
3a	1.7	0.65	4	75.1	48.9	124.0	21.3	60.8	82.1	-52.9	172.1	119.2
4a	1.3	0.60	4	43.2	47.0	90.2	2.6	58.0	60.6	-56.0	159.8	103.9
5a	1.0	0.55	4	20.9	43.6	64.5	-9.9	53.9	44.0	-56.9	146.6	89.7
6a	0.8	0.60	4	-5.7	55.3	49.6	-28.5	65.3	36.8	-66.0	164.1	98.1
7a	1.0	0.58	4	16.6	48.5	65.1	-13.7	58.9	45.2	-60.0	156.0	95.9
8a	0.6	0.47	4	-7.1	36.9	29.9	-24.9	46.1	21.2	-56.5	124.9	68.3
9a	2.8	0.35	3	272.5	6.4	278.9	160.9	12.7	173.6	22.0	83.4	105.4
10a	1.3	0.35	4	83.4	14.2	97.6	38.1	22.3	60.4	-24.6	87.3	62.7
11a	0.8	0.35	4	32.1	18.2	50.3	5.1	26.4	31.5	-36.6	89.1	52.4
with shutter												
1b	5.8	0.85	2	406.9	2.4	409.3	243.7	15.6	259.3	30.4	86.2	116.6
2b	2.8	0.78	3	142.1	7.5	149.6	69.9	25.0	94.8	-31.5	78.4	46.9
3b	1.7	0.65	4	52.7	8.8	61.5	14.2	24.4	38.5	-44.2	65.5	21.3
4b	1.3	0.60	4	29.9	8.8	38.6	0.6	23.3	24.0	-46.1	60.6	14.5
5b	1.0	0.55	4	13.2	8.3	21.5	-8.7	21.8	13.0	-46.4	55.5	9.1
6b	0.8	0.60	4	-10.4	12.0	1.7	-26.2	27.2	1.0	-55.9	61.3	5.3
7b	1.0	0.58	4	8.9	9.6	18.5	-12.6	24.0	11.3	-49.7	58.8	9.0
8b	0.6	0.47	4	-9.1	7.3	-1.8	-20.7	18.8	-1.9	-45.5	47.4	1.8
9b	2.8	0.35	3	217.0	0.6	217.6	131.9	5.1	137.0	22.8	36.1	58.9
10b	1.3	0.35	4	70.2	2.1	72.2	35.5	8.8	44.3	-15.3	34.5	19.2
11b	0.8	0.35	4	27.7	2.9	30.6	7.7	10.5	18.2	-26.1	34.5	8.4

For facade windows with ventilative cooling, and low Uenv values (modern homes).

Table 17 Calculation energy performance of façade windows, with/without shutters single family house, U_{env}=0,3 W/(m²K) Climate North; U_{env}=0,4 W/(m²K) Climate Central; U_{env}=0,6 W/(m²K) Climate South, ventilative cooling

No.	U_w in W/(m²K)	g	Airtightness class	Energy use in kWh/(m² a)related to m² window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	581.3	10.0	591.3	343.7	24.9	368.7	48.5	183.8	232.3
2a	2.8	0.78	3	197.1	14.3	211.4	96.1	29.9	126.0	-35.9	172.6	136.8
3a	1.7	0.65	4	75.6	11.2	86.8	21.7	24.1	45.8	-52.6	142.3	89.8
4a	1.3	0.60	4	43.6	9.8	53.3	2.9	21.6	24.5	-55.7	130.6	74.9
5a	1.0	0.55	4	21.2	8.2	29.4	-9.6	18.8	9.2	-56.6	118.7	62.0
6a	0.8	0.60	4	-5.2	10.9	5.7	-28.2	23.1	-5.1	-65.7	131.8	66.0
7a	1.0	0.58	4	17.0	9.5	26.5	-13.4	21.0	7.6	-59.7	126.2	66.5
8a	0.6	0.47	4	-6.9	5.8	-1.0	-24.7	14.5	-10.2	-56.4	99.5	43.1
9a	2.8	0.35	3	272.7	1.6	274.3	160.9	6.1	166.9	22.1	73.5	95.6
10a	1.3	0.35	4	83.5	2.1	85.7	38.2	7.3	45.4	-24.5	71.3	46.7
11a	0.8	0.35	4	32.2	2.5	34.6	5.2	7.8	13.0	-36.6	71.0	34.4
with shutter												
1b	5.8	0.85	2	406.9	0.9	407.8	230.7	11.0	241.7	30.4	80.9	111.2
2b	2.8	0.78	3	142.2	1.1	143.3	61.1	11.7	72.8	-31.5	67.7	36.2
3b	1.7	0.65	4	52.8	0.8	53.6	7.3	9.4	16.7	-44.3	54.1	9.8
4b	1.3	0.60	4	30.0	0.7	30.7	-5.8	8.4	2.7	-46.1	49.3	3.2
5b	1.0	0.55	4	13.3	0.6	13.9	-14.8	7.5	-7.3	-46.4	44.6	-1.8
6b	0.8	0.60	4	-10.1	0.8	-9.4	-31.5	8.9	-22.6	-56.0	48.5	-7.4
7b	1.0	0.58	4	9.0	0.7	9.7	-18.5	8.2	-10.3	-49.8	47.1	-2.6
8b	0.6	0.47	4	-9.0	0.5	-8.6	-26.2	6.0	-20.2	-45.6	37.2	-8.3
9b	2.8	0.35	3	217.0	0.2	217.2	124.6	3.2	127.9	22.8	33.8	56.6
10b	1.3	0.35	4	70.1	0.2	70.3	29.4	3.5	32.9	-15.3	29.1	13.8
11b	0.8	0.35	4	27.7	0.2	27.9	2.2	3.7	5.8	-26.1	28.0	1.9

Change in setpoint of shading activation

Analysing the results given in Table 14 to Table 17 it can be seen, that especially in the Southern climate, but also in the Central climate the energy performance for heating is worse for windows with a shutter compared to windows without a shutter. The reason for that is that the shutter was activated during daytime in the transition period, although there was a need for heating of the building. To avoid this, the set point of the external temperature for the activation of the shutter during daytime was increased to 20°C and further calculations of the energy performance were performed. The following tables are showing the results for the calculation of the energy performance with the accordingly changed set point.

In general it is assumed, that a shutter/sun shading is not used within the heating period during daytime, reducing the solar gains.

For facade windows without ventilative cooling, and high Uenv values (older homes), and setpoint shading activation during heating changed.

Table 18 Calculation energy performance of façade windows, with/without shutters single family house, U_{env}=0,6 W/(m^{2}K) Climate North; U_{env}=0,8 W/(m^{2}K) Climate Central; U_{env}=1,0 W/(m^{2}K) Climate South, no ventilative cooling

No.	U_w in W/(m^{2}K)	g	Airtightness class	Energy use in kWh/(m^2 a)related to m^2 window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	546.2	14.3	560.5	316.0	27.1	343.1	35.4	180.6	216.0
2a	2.8	0.78	3	170.0	25.5	195.5	72.4	37.0	109.4	-53.6	174.0	120.3
3a	1.7	0.65	4	51.2	22.7	73.9	0.5	32.0	32.5	-70.5	145.5	75.0
4a	1.3	0.60	4	21.0	20.7	41.7	-16.8	29.3	12.5	-73.0	134.1	61.2
5a	1.0	0.55	4	0.5	18.1	18.6	-27.8	26.1	-1.7	-72.9	122.4	49.4
6a	0.8	0.60	4	-28.2	24.2	-4.1	-48.4	32.2	-16.2	-84.8	136.1	51.3
7a	1.0	0.58	4	-4.9	20.8	15.9	-32.6	29.0	-3.6	-77.3	130.1	52.8
8a	0.6	0.47	4	-24.4	13.8	-10.6	-40.3	20.8	-19.6	-70.6	103.2	32.6
9a	2.8	0.35	3	253.6	2.5	256.1	146.4	7.7	154.1	15.6	73.1	88.7
10a	1.3	0.35	4	68.8	4.9	73.7	25.9	10.3	36.2	-32.6	73.1	40.5
11a	0.8	0.35	4	18.8	6.0	24.8	-6.5	11.4	5.0	-45.5	73.6	28.1
with shutter												
1b	5.8	0.85	2	374.9	2.4	377.3	209.8	12.6	222.4	-6.2	79.7	73.4
2b	2.8	0.78	3	114.3	6.2	120.5	40.4	15.3	55.7	-65.6	69.1	3.5
3b	1.7	0.65	4	27.3	5.5	32.9	-11.7	13.1	1.5	-75.0	56.2	-18.8
4b	1.3	0.60	4	6.2	4.9	11.1	-23.3	12.1	-11.2	-75.3	51.4	-23.9
5b	1.0	0.55	4	-8.6	4.1	-4.6	-30.9	10.9	-20.0	-73.9	46.7	-27.2
6b	0.8	0.60	4	-34.3	6.6	-27.7	-49.6	13.2	-36.4	-85.2	51.3	-33.9
7b	1.0	0.58	4	-14.1	5.1	-9.0	-35.7	12.0	-23.7	-78.3	49.5	-28.8
8b	0.6	0.47	4	-27.8	2.8	-25.0	-39.9	8.9	-30.9	-70.1	39.2	-30.9
9b	2.8	0.35	3	197.5	0.5	198.0	112.9	4.0	116.9	2.5	33.2	35.7
10b	1.3	0.35	4	54.1	0.9	55.0	19.0	5.0	24.0	-35.0	29.8	-5.3
11b	0.8	0.35	4	13.0	1.1	14.0	-7.8	5.5	-2.3	-45.6	29.1	-16.6

For facade windows with ventilative cooling, and high Uenv values (older homes), and setpoint shading activation during heating changed.

Table 19 Calculation energy performance of façade windows, with/without shutters single family house, U_{env}=0,6 W/(m^{2}K) Climate North; U_{env}=0,8 W/(m^{2}K) Climate Central; U_{env}=1,0 W/(m^{2}K) Climate South, ventilative cooling

No.	U_w in W/(m^{2}K)	g	Airtightness class	Energy use in kWh/(m^2 a)related to m^2 window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	546.8	7.3	554.1	316.6	19.4	336.0	35.8	167.9	203.7
2a	2.8	0.78	3	170.3	9.3	179.6	72.8	21.0	93.8	-53.2	153.8	100.6
3a	1.7	0.65	4	51.6	6.9	58.4	0.7	16.1	16.8	-70.3	125.5	55.2
4a	1.3	0.60	4	21.4	5.8	27.2	-16.7	14.3	-2.4	-72.8	114.8	42.1
5a	1.0	0.55	4	0.8	4.9	5.7	-27.8	12.3	-15.4	-72.7	104.1	31.3
6a	0.8	0.60	4	-27.9	6.4	-21.5	-48.2	15.0	-33.3	-84.6	115.2	30.5
7a	1.0	0.58	4	-4.6	5.6	1.1	-32.5	13.7	-18.8	-77.1	110.6	33.5
8a	0.6	0.47	4	-24.1	3.4	-20.7	-40.3	9.4	-30.9	-70.4	86.9	16.5
9a	2.8	0.35	3	253.9	1.0	254.9	146.4	4.5	151.0	15.6	66.8	82.5
10a	1.3	0.35	4	69.1	1.3	70.4	25.9	5.1	30.9	-32.6	63.4	30.8
11a	0.8	0.35	4	19.2	1.5	20.6	-6.5	5.2	-1.3	-45.4	62.7	17.3
with shutter												
1b	5.8	0.85	2	375.2	0.9	376.2	209.9	8.8	218.7	-6.2	75.0	68.8
2b	2.8	0.78	3	114.7	1.1	115.8	40.3	8.5	48.9	-65.6	61.4	-4.2
3b	1.7	0.65	4	27.7	0.8	28.5	-11.8	6.6	-5.1	-75.0	48.6	-26.4
4b	1.3	0.60	4	6.6	0.7	7.3	-23.4	5.9	-17.5	-75.3	44.1	-31.1
5b	1.0	0.55	4	-8.3	0.6	-7.7	-31.0	5.2	-25.7	-73.9	39.9	-34.0
6b	0.8	0.60	4	-33.9	0.8	-33.2	-49.7	6.1	-43.5	-85.2	43.2	-42.0
7b	1.0	0.58	4	-13.8	0.7	-13.1	-35.8	5.7	-30.0	-78.3	42.1	-36.2
8b	0.6	0.47	4	-27.6	0.4	-27.2	-40.0	4.2	-35.8	-70.1	33.2	-36.9
9b	2.8	0.35	3	197.7	0.1	197.8	112.8	2.6	115.4	2.5	31.4	33.9
10b	1.3	0.35	4	54.3	0.2	54.4	18.9	2.7	21.6	-35.0	26.6	-8.5
11b	0.8	0.35	4	13.1	0.2	13.3	-7.9	2.7	-5.1	-45.6	25.4	-20.3

For facade windows without ventilative cooling, and low Uenv values (modern homes), and setpoint shading activation during heating changed.

Table 20 Calculation energy performance of façade windows, with/without shutters single family house, U_{env}=0,3 W/(m^{2}K) Climate North; U_{env}=0,4 W/(m^{2}K) Climate Central; U_{env}=0,6 W/(m^{2}K) Climate South, no ventilative cooling

No.	U_w in W/(m^{2}K)	g	Airtightness class	Energy use in kWh/(m^2 a)related to m^2 window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	580.9	23.5	604.4	343.1	39.4	382.5	48.0	200.6	248.6
2a	2.8	0.78	3	196.7	48.8	245.5	95.4	63.5	158.9	-36.3	201.5	165.2
3a	1.7	0.65	4	75.1	48.9	124.0	21.3	60.8	82.1	-52.9	172.1	119.2
4a	1.3	0.60	4	43.2	47.0	90.2	2.6	58.0	60.6	-56.0	159.8	103.9
5a	1.0	0.55	4	20.9	43.6	64.5	-9.9	53.9	44.0	-56.9	146.6	89.7
6a	0.8	0.60	4	-5.7	55.3	49.6	-28.5	65.3	36.8	-66.0	164.1	98.1
7a	1.0	0.58	4	16.6	48.5	65.1	-13.7	58.9	45.2	-60.0	156.0	95.9
8a	0.6	0.47	4	-7.1	36.9	29.9	-24.9	46.1	21.2	-56.5	124.9	68.3
9a	2.8	0.35	3	272.5	6.4	278.9	160.9	12.7	173.6	22.0	83.4	105.4
10a	1.3	0.35	4	83.4	14.2	97.6	38.1	22.3	60.4	-24.6	87.3	62.7
11a	0.8	0.35	4	32.1	18.2	50.3	5.1	26.4	31.5	-36.6	89.1	52.4
with shutter												
1b	5.8	0.85	2	401.1	6.5	407.7	230.5	19.1	249.6	6.2	87.8	94.0
2b	2.8	0.78	3	139.4	24.2	163.6	60.8	32.4	93.1	-47.7	81.1	33.4
3b	1.7	0.65	4	50.7	25.8	76.4	7.1	31.4	38.6	-57.5	68.0	10.5
4b	1.3	0.60	4	28.0	24.9	52.8	-5.9	30.0	24.1	-58.6	62.9	4.2
5b	1.0	0.55	4	11.5	22.9	34.3	-14.8	27.7	12.9	-58.4	57.6	-0.8
6b	0.8	0.60	4	-11.9	31.6	19.7	-31.6	34.9	3.2	-66.9	64.0	-2.9
7b	1.0	0.58	4	7.2	26.3	33.5	-18.6	30.7	12.1	-61.6	61.1	-0.5
8b	0.6	0.47	4	-10.7	18.9	8.2	-26.3	23.7	-2.6	-56.9	49.0	-7.9
9b	2.8	0.35	3	213.5	1.2	214.6	124.7	5.9	130.6	8.3	36.5	44.8
10b	1.3	0.35	4	67.8	4.7	72.5	29.4	10.4	39.8	-27.6	35.3	7.7
11b	0.8	0.35	4	25.8	6.9	32.7	2.2	12.6	14.8	-37.6	35.4	-2.2

For facade windows with ventilative cooling, and low Uenv values (modern homes), and setpoint shading activation during heating changed.

Table 21 Calculation energy performance of façade windows, with/without shutters single family house, U_{env}=0,3 W/(m^2K) Climate North; U_{env}=0,4 W/(m^2K) Climate Central; U_{env}=0,6 W/(m^2K) Climate South, ventilative cooling

No.	U_w in W/(m^2K)	g	Airtightness class	Energy use in kWh/(m^2 a)related to m^2 window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	581.3	10.0	591.3	343.7	24.9	368.7	48.5	183.8	232.3
2a	2.8	0.78	3	197.1	14.3	211.4	96.1	29.9	126.0	-35.9	172.6	136.8
3a	1.7	0.65	4	75.6	11.2	86.8	21.7	24.1	45.8	-52.6	142.3	89.8
4a	1.3	0.60	4	43.6	9.8	53.3	2.9	21.6	24.5	-55.7	130.6	74.9
5a	1.0	0.55	4	21.2	8.2	29.4	-9.6	18.8	9.2	-56.6	118.7	62.0
6a	0.8	0.60	4	-5.2	10.9	5.7	-28.2	23.1	-5.1	-65.7	131.8	66.0
7a	1.0	0.58	4	17.0	9.5	26.5	-13.4	21.0	7.6	-59.7	126.2	66.5
8a	0.6	0.47	4	-6.9	5.8	-1.0	-24.7	14.5	-10.2	-56.4	99.5	43.1
9a	2.8	0.35	3	272.7	1.6	274.3	160.9	6.1	166.9	22.1	73.5	95.6
10a	1.3	0.35	4	83.5	2.1	85.7	38.2	7.3	45.4	-24.5	71.3	46.7
11a	0.8	0.35	4	32.2	2.5	34.6	5.2	7.8	13.0	-36.6	71.0	34.4
with shutter												
1b	5.8	0.85	2	401.5	1.4	402.9	230.7	11.0	241.7	6.2	81.3	87.5
2b	2.8	0.78	3	139.9	1.9	141.7	61.1	11.7	72.8	-47.5	68.3	20.8
3b	1.7	0.65	4	51.1	1.4	52.5	7.3	9.4	16.7	-57.3	54.6	-2.8
4b	1.3	0.60	4	28.4	1.2	29.6	-5.8	8.4	2.7	-58.5	49.7	-8.9
5b	1.0	0.55	4	11.8	1.0	12.8	-14.8	7.5	-7.3	-58.3	44.9	-13.4
6b	0.8	0.60	4	-11.4	1.3	-10.1	-31.5	8.9	-22.6	-66.8	49.0	-17.8
7b	1.0	0.58	4	7.6	1.2	8.8	-18.5	8.2	-10.3	-61.4	47.5	-13.9
8b	0.6	0.47	4	-10.5	0.7	-9.7	-26.2	6.0	-20.2	-56.9	37.5	-19.4
9b	2.8	0.35	3	213.6	0.2	213.8	124.6	3.2	127.9	8.3	33.9	42.1
10b	1.3	0.35	4	67.9	0.3	68.2	29.4	3.5	32.9	-27.6	29.2	1.6
11b	0.8	0.35	4	25.8	0.3	26.1	2.2	3.7	5.8	-37.6	28.1	-9.5

The calculations based on the single family house (Table 18 to Table 21) show that the best (lowest total energy consumption, without consideration of costs) available technology for facade windows

A) with a shutter/sun shading:

1. for Climate North and Central: Openable window with very low U-value and high g-value, moveable external shutter
2. for condition South: Openable window with low U-value and high g-value, moveable external shutter/sun shading device.

B) without a shutter/sun shading:

1. for Climate North and Central: Openable window with very low U-value and high g-value
2. for condition South: Openable window with low U-value and low g-value.

(openable means that ventilative cooling may take place through window)

3.2.8. BAT FOR HEATING AND COOLING PERFORMANCE OF ROOF WINDOWS IN RESIDENTIAL BUILDINGS BASED ON THE SINGLE FAMILY HOUSE

As explained above, it is not possible to separate between different orientations and/or different inclinations using the adiabatic approach in combination with the single family house. Therefore no BAT calculations for roof windows using the single family house approach in combination with the 'adiabatic' calculation method, could be performed.

3.2.9. CONCLUSION BAT

Small variations of the boundary conditions do not lead to significant different ranking of the investigated design options. Therefore the BAT definition can be used for buildings, <u>where the assumed boundary conditions are representative and for buildings where the boundary conditions only vary within certain limits</u>. Residential buildings are fulfilling these requirements in general.

Summarising the performed calculations the following conclusions can be drawn:

- For climate North and Central the BAT is for all investigated different building approaches (single room, single family house): Openable window with very low U-value and high g-value, moveable external shutter
- For Climate South: The BAT differs depending on the building approach. For the single room approach the BAT is an openable window with low U-value and low g-value, moveable external shutter/sun shading device. For the approach considering a single family house the BAT is an openable window with very low U-value and high g-value, moveable external shutter
- The proportions of the heating energy and the cooling energy to the combined energy are influenced by the ratio of heat gains to the heat losses of the building. For buildings with low heat losses, e.g. low U-values of the building envelope, compact buildings (multi family houses => single room approach), no ventilative cooling the proportion of the cooling energy is increasing compared to buildings with higher heat losses.

3.3. BEST NOT YET AVAILABLE TECHNOLOGIES

In chapter 4.1.6 of the MEErP 2011 METHODOLOGY PART 1 FINAL report the following definition of best not (yet) available technology (BNAT) is given:

The BNAT point indicates the space for future innovation and product-differentiation after the introduction of measures. Should the measures be too ambitious, i.e. allow only the BAT products with no long-term perspective on new improved products, the conclusion can be that indeed there is a negative impact for the consumer (no freedom-of-choice) and for business (only one product type with necessarily a large focus on low-cost production).

Furthermore, it is not excluded that BNAT technologies can be taken up in certain incentive programs once they have been evaluated as such in the Ecodesign preparatory study.

Finally, the BNAT-level can be an indicator for future new energy classes ('A+', 'A++', 'A+++').

When analysing the best not yet available technologies it has to be kept in mind that it is not only a question of the technology itself, but also a question of the availability of a significant quantity of products with a sophisticated technology.

In particular the following two technologies promise to possibly have a major impact on the energy related characteristics of windows

- Switchable glazings and;
- Vacuum glazings.

Switchable glazings

The general technology was already described in 3.1.4. Although there are two companies selling such products, it has to be stated, that these products <u>are currently used in niche markets</u>. It must be assumed, that production capacity is limited.

To control the properties of switchable glazing's a low voltage supply is needed. Therefore the installation of the glazing in an open able sash has also to consider the installation of the wires within the window. There are simple solutions for that.

The glazing can be assessed on the basis of existing standards and its properties can be used to determine the performance.

Vacuum glazing

In a vacuum insulation glazing two glass panes, connected by an airtight edge seal, are evacuated to a pressure of below 10-3mbar. The panes, one or two coated with a highly infrared-reflecting layer to minimize thermal radiation, are supported by a matrix of spacers to prevent collapse.

The high vacuum must be sustained for the complete use phase of the glazing 20 to 25 years. This result in very high requirements on the edge seal; new techniques not used for conventional IGU must be applied.

Because of the high requirements in the tightness of the edge seal a production process is highly sophisticated. The process itself could have restrictions on the available dimensions and geometries of vacuum glass.

Theoretical analysis show, that an optimized vacuum glass could achieve U values of about 0.4 W/m^2K; the total solar energy transmittance would be as high as for conventional double IGU. Besides the low U-value and high g-value a further major advantage would be, that the thickness of a vacuum glass could be reduced to 6-8 mm. Therefore such a system would be perfect for the exchange of the glazing of a window only.

For the time being there is only one system available on the European market. Spacia is the brand of the product being sold by Pilkington. The thermal transmittance of Spacia is in the range of with U_g = 0.9 to 1.5 W/m^2K depending on the emissivity of the applied low e-coating. Also the g value depends on the coating. According to the website of Pilkington a g-value of g = 0.67 can be achieved with a U value of U_g = 1.5 W/m^2K. The thickness is 6.5 mm.

Currently the system itself is produced in Japan but not in Europe. Therefore the time between the order and delivery is 8-10 weeks in general. The price per square meter is in the range of 250 to 420 € and therefore approximately 10 times the price for conventional double IGU.

The glazing can be assessed on the basis of existing standards and its properties can be used to determine the performance.

***

Glass fibre reinforced plastic window frames

A third direction for improvement may be the development of windows with alternative frame materials such as glass fibre reinforced plastics (GFRP) or frames made of wood-polymer composites (WPC) which may allow production of slim frames[12]. At least GFRP windows are placed on the market commercially[13], but their market significance is considered to be modest at most, which is why they are mentioned under this heading. The performance of such windows can be assessed on the basis of existing standards.

The study "Development of a slim window frame made of glass fibre reinforced polyester"[14] presented information on the energy performance of this type of window compared to other 'standard' windows. One of the main benefits mentioned in this study is the reduced frame fraction. The study did not present detailed life cycle analysis information.

[12] This may mean "pultruded fiberglass frame completely filled with laser die cut polystyrene, injection moulded reinforced mechanical welded corners with polyurethane foam fill, sealed with silicone sealant (Source: www.fibertec.com).

[13] Based on information taken from: www.protecwindows.com, www.fibertec.com, www.awa.org.au/industry-sectors/fibreglass

[14] David Appelfeld, Christian S. Hansen, Svend Svendsen, Development of a slim window frame made of glass fibre reinforced polyester, Department of Civil Engineering, Technical University of Denmark, Brovej, Building 118, DK-2800 Kgs. Lyngby, Denmark, 26 May 2010.

CHAPTER 4 PRODUCTION, DISTRIBUTION AND END OF LIFE

4.1. PRODUCTION

4.1.1. TRANSPARENT FILLING ELEMENTS

→ **Flat glass, toughened safety glass and laminated safety glass**

A) Product descriptions

"Flat glass" (FG) refers to both uncoated and coated float glass. Float glass is a clear, flat soda lime silicate glass with parallel, fire-polished surfaces, in some cases bearing metal-oxide-based coatings to modify the radiation (thermal insulation and/or solar control) properties of the glass.

Toughened safety glass (TSG) consists of a single pane that has been specially heat-treated to give the glass increased impact resistance. If the glass breaks under exposure to a high load, it disintegrates into very small fragments with no sharp edges.

Laminated safety glass (LSG) consists of at least two glass panes lying one on top of the other, with one or several layers of a tear-resistant, toughened film, usually polyvinyl butyral (PVB), positioned between the panes.

Cutting/characteristics:

Flat glass is generally supplied in stock sizes of 600 x 321 cm. It is cut and processed into toughened safety glass or laminated safety glass on a project-specific basis.

B) Production process

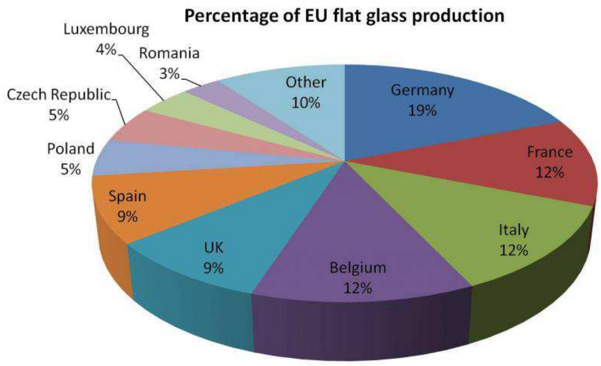
The main components of float glass are the naturally occurring raw materials sand (silicon carbonate, 59%), soda (sodium carbonate, 18%), dolomite (15%), limestone (calcium carbonate, 4%), nepheline (3%) and sulfate (1%).

The raw materials are introduced as a mixture into the furnace where they are melted at a temperature of approx. 1560 °C, generally using gas as an energy resource. The glass is shaped by distributing the mass of liquid glass over a bath of molten tin. The glass sheet is then cooled evenly and cut to size.

Coated glass is float glass that has been coated with a metal-oxide-based coating using various processes (sputtering, evaporation, pyrolytic processes). The coating is a few atom layers thick.

Nearly 3/4 of the flat glass produced in the EU is produced in Germany, France, Italy, Belgium, the UK, Spain and Poland.

Figure 37: percentage of EU flat glass production[15]



[15] Source: Final report: "EPDs for transparent construction elements", **ift** Rosenheim

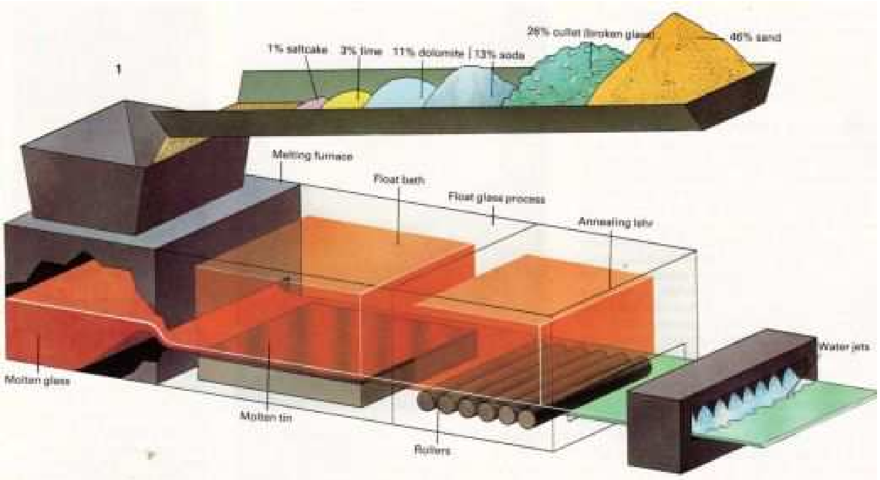
For the manufacture of TSG, float glass is heated to its transition temperature (min. 640 °C) and then rapidly cooled. This causes the surfaces of the glass to cool and contract faster than the remaining material. This creates additional compressive strength in the surfaces that makes the resulting glass tougher.

For the manufacture of LSG, a PVB film is placed between the panes of glass and these are pressed together in an autoclave under the action of heat and pressure.

The manufacturing processes described are applicable to all manufacturing sites of all manufacturers in Europe, because no production processes are used for the manufacture of FG, TSG and LSG that differ significantly from the above.

If used according to their intended use, flat glass, TSG and LSG can be expected to have a service life of more than 50 years

Figure 38: Illustration of the float glass process[16]

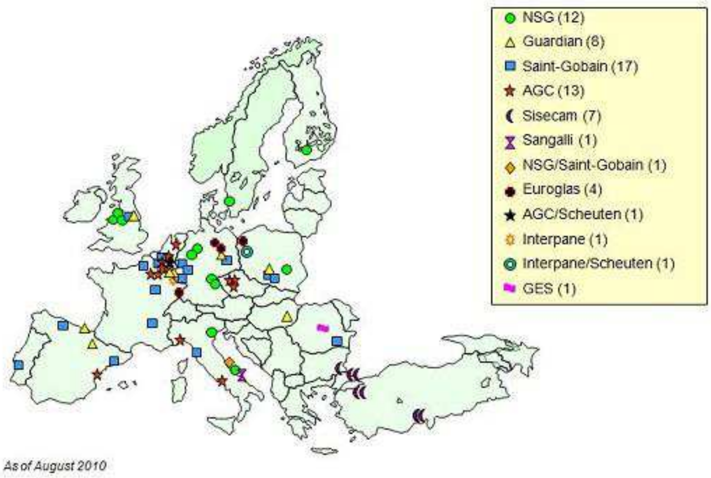


C) Distribution process

Nine companies operate float glass production facilities in the European Union or candidate countries. The location of these facilities is presented in the next figure

Considering these geographical positions and taking into account the market need for float glass in Europe it can be assumed, that an average distance for shipment of float glass (also coated float glass) is not more than 500 km. For the transport trucks with a capacity of about 25 to 30 t are used. Estimating a degree of capacity of 85% seems reasonable.

Figure 39: Location of float lines in Europe[17]



[16] Source: http://www.artinaid.com/2013/04/glass/ Creative Commons Attribution-ShareAlike 3.0 Unported License

[17] Source: Final report: "EPDs for transparent construction elements", **ift** Rosenheim

→ **Insulating glazing units (IGU)**

A) Product descriptions

An IGU consists of two or several glass panes separated from one another by one or several cavities containing an air or gas filling. The panes are hermetically sealed (air/vapour and moisture proof) using e.g. organic sealing compounds.

B) Production process

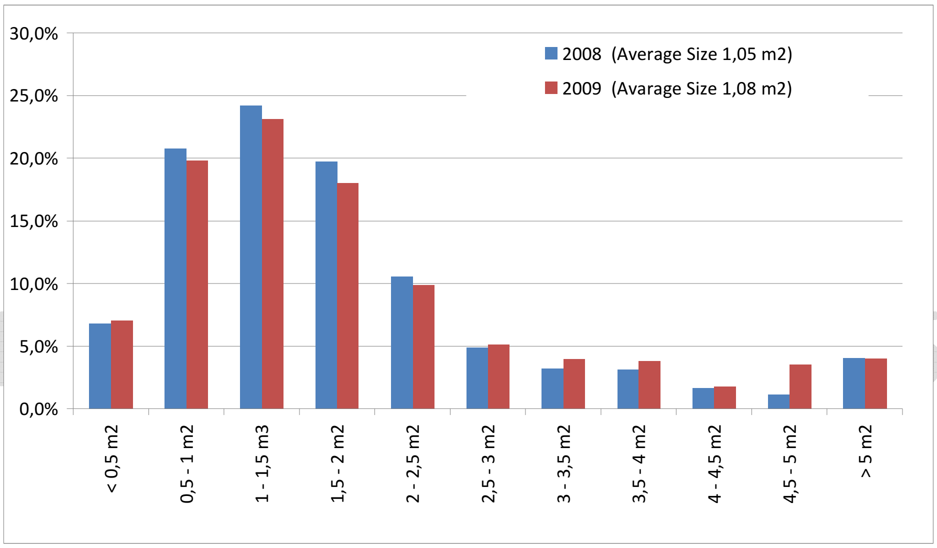
Glass panes are positioned the desired distance apart using one or several spacer profiles made from aluminium, stainless steel or a plastic/metal combination, or containing organic materials, and are joined and sealed in a vapour-proof manner using in general two sealing panes, following the filling of the cavities with noble gas (generally argon).

The manufacturing processes described are applicable to all manufacturing sites of all manufacturers in Europe, because no production processes are used for the manufacture of FG, TSG and LSG that differ significantly from the above.

If used according to their intended use, insulating glass units can be expected to have a service life of 25 to 30 years.

Figure 40 shows the distribution of dimension of produced IGUs in Germany in the years 2008/2009. Over 60% of the produced IGUs have a dimension in the range of 0.5 to 2 m^2.

Figure 40: Distribution of dimensions of produced IGUs in Germany[18]



C) Distribution process

In general Insulation glazing units are shipped to the window manufacturer with trucks. The glazing's are placed on special racks and do not have any packaging. For the further analysis in Task 5 and Task 6 an average distance of 200 km can be assumed.

[18] Source: Final report: "EPDs for transparent construction elements", **ift** Rosenheim

4.1.2. Windows

→ **Wooden windows**

Manufacturing of the scantlings:

1. Cutting: Cut the slats from wooden boards.
2. Drying: drying of the slats in a drying chamber.
3. Planing: Planing the slats.
4. Scanning and capping: Scan the slats on wood defects (knots, cracks) and cut out the errors. Milling the joint and gluing the pieces to a plate. Cutting the plates on a standard length.
5. Siping: gluing the slats to a scantling
6. Finish: planing the glued scantlings. Profiling of the scantlings

Manufacturing of the window:

1. Profiling: The incoming scantlings or solid wood profiles are profiled. Cutting the profiles.
2. Corner joint: milling or drilling the corner joint
3. Bonding: Bonding and molding the frame.
4. Milling: Milling of the rebate and drilling the fitting recesses
5. Surface coating: priming and painting the frames according to different application methods. It is the usual to dip spray or brush.
6. Drying: Drying the painted frame in dependence of the coating system. Heat dryer or air drying.
7. Final assembly: Final assembly of all window components such as gaskets, fittings, glass. Subsequent final inspection of the window.

If used according to their intended use and with proper maintenance, timber windows can be expected to have a service life of 50 years.

Wooden windows must be repainted every 3 to 6 years, depending on their exposure (position in the building and the wall), colour and type of wood. Sometimes the interval could be enlarged.

→ **Aluminium windows**

Manufacturing of the frame profiles:

1. Heating: Source materials are semi-finished products (extrusion) made of aluminium. The material is heated to about 480 ° C.
2. Presses: The heated strand pressed at very high pressure (up to 4000 tons) through a die.
3. Thermal treatment: The properties of the profiles are improved by thermal treatment in special furnaces.
4. Merging: The individual aluminium profiles are joined together with a thermal break (only for profiles with a thermal break).

Manufacturing of the window:

1. Surface treatment: The aluminium profiles are either anodized or powder coated.
2. Cutting: The profiles are cut off to the desired length.
3. Milling: The drainage and fitting openings are processed.
4. Bonding / welding: The profiles are either mainly mechanically connected with corner connections and glue or welded.
5. Final assembly: Final assembly of all window components such as seals, Fittings, Glass. Subsequent final inspection of the window.

→ **Plastic windows**

Manufacturing of the frame profiles (PVC):

1. Mixing: The raw materials are dried, weighed and mixed together homogeneously.
2. Extrusion: The raw materials are plasticized in a extruder screw and formed over a die to plastic profiles.
3. Disconnect: The profiles are drawn off via a trigger unit and cut by a saw.
   Surface treatment (optional): primer, paint, drying / bonding of foils

Manufacturing of the window (PVC):

1. Cutting: Supplied profiles by the system provider are cut to the desired length.
2. Gland: Attachment of the locking plates and union of the profiles with the reinforcements.
3. Welding: Welding of profiles with finishing the weld.
4. Final assembly: Final assembly of all window components such as gaskets, fittings, glass. Subsequent final inspection of the window.

Manufacturing of PUR windows (as a roof window variety):

1. Manufacturing of timber core (see manufacturing of scantlings)
2. Moulding of PUR frame around the timber core
3. Surface treatment with lacquer
4. Final assembly of all window components such as gaskets, fitting and insulation glass units

If used according to their intended use and with proper maintenance, plastic windows can be expected to have a service life of 50 years.

4.2. PRODUCT WEIGHT AND BILLS OF MATERIAL

The data presented in this chapter is mainly based on the study "The development of environmental product declarations for transparent construction elements –windows and glass – for assessing the sustainability of buildings, funded by the research initiative of future-oriented construction "Zukunft Bau" of the Federal Institute for Research on Building, Urban Affairs and Spatial Development, Germany and on the EPDs published by **ift** Rosenheim in the last 3 years.

4.2.1. COMPONENTS/ MATERIALS USED FOR WINDOWS

The following figures present the main components and materials used to produce:

- Glazing elements (Figure 41)
- Hardware (Figure 4-6)
- Timber windows (

- Figure 43 and Figure 4-8),
- Plastic windows (Figure 4-9 and Figure 46) and
- Metal windows (Figure 4-11 and Figure 4-12)

Figure 41: Different components of a glazing (IGU)

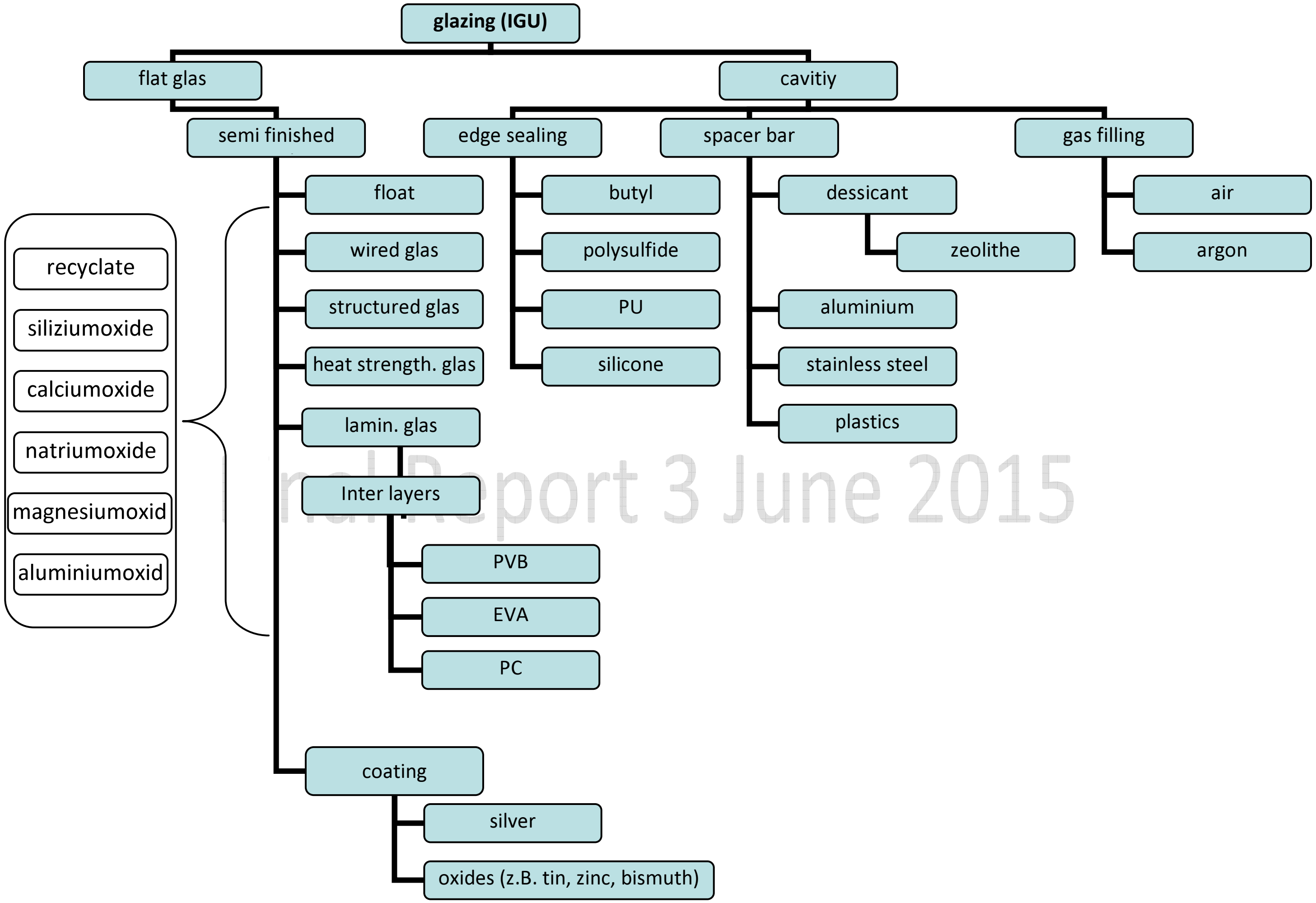


Figure 42: Different components of the hardware

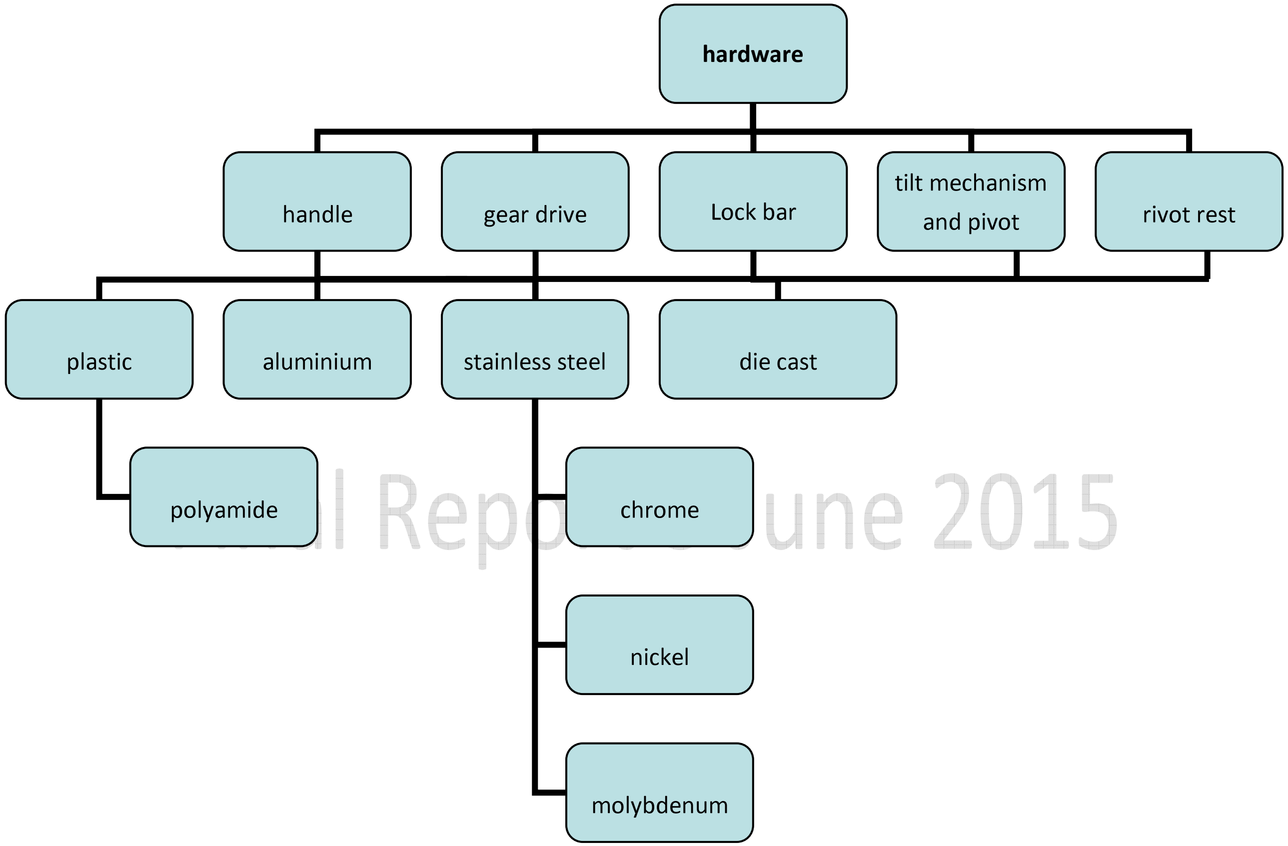


Figure 43: Different components of a timber window

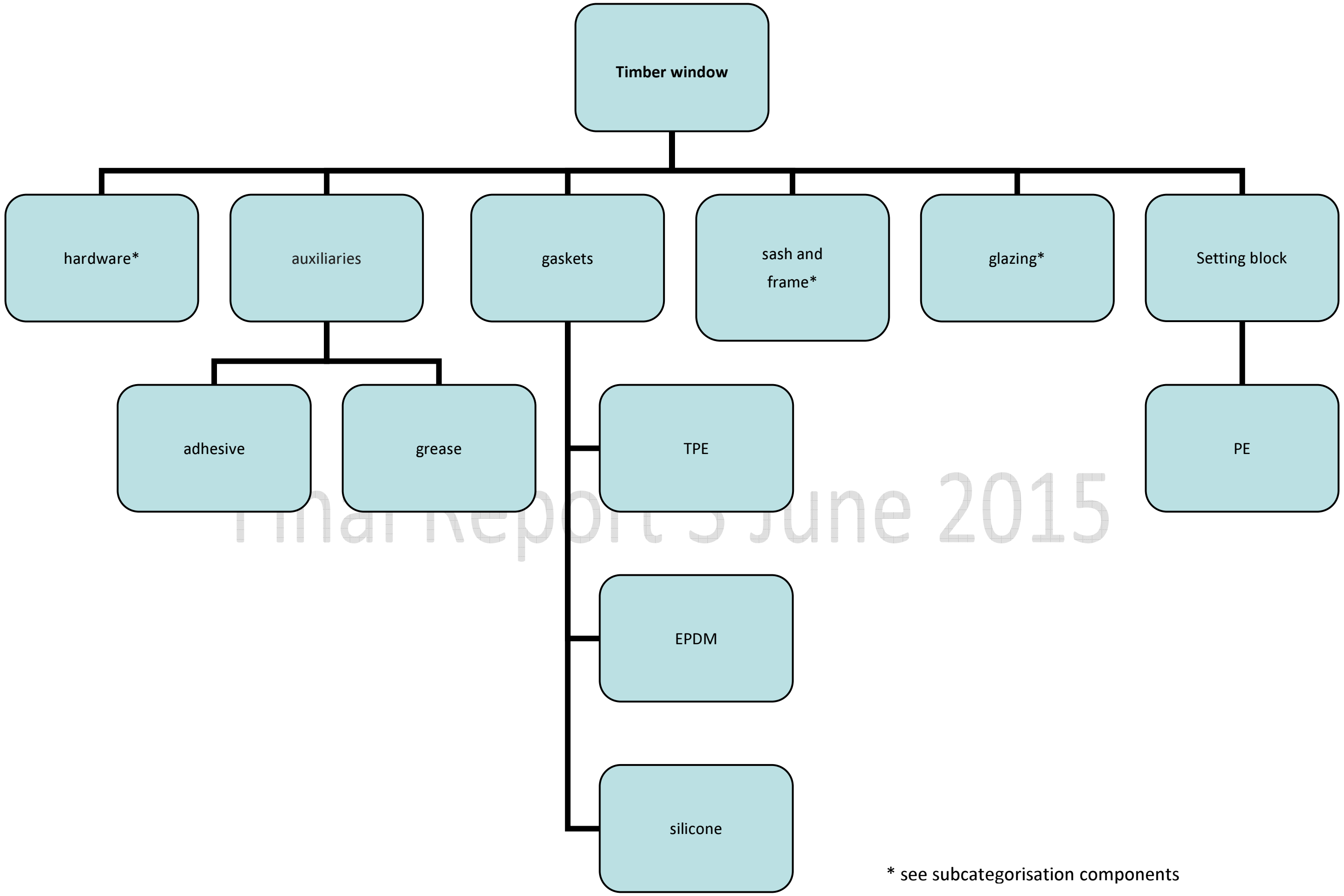


Figure 44: Different components of the sash/frame combination of a timber window

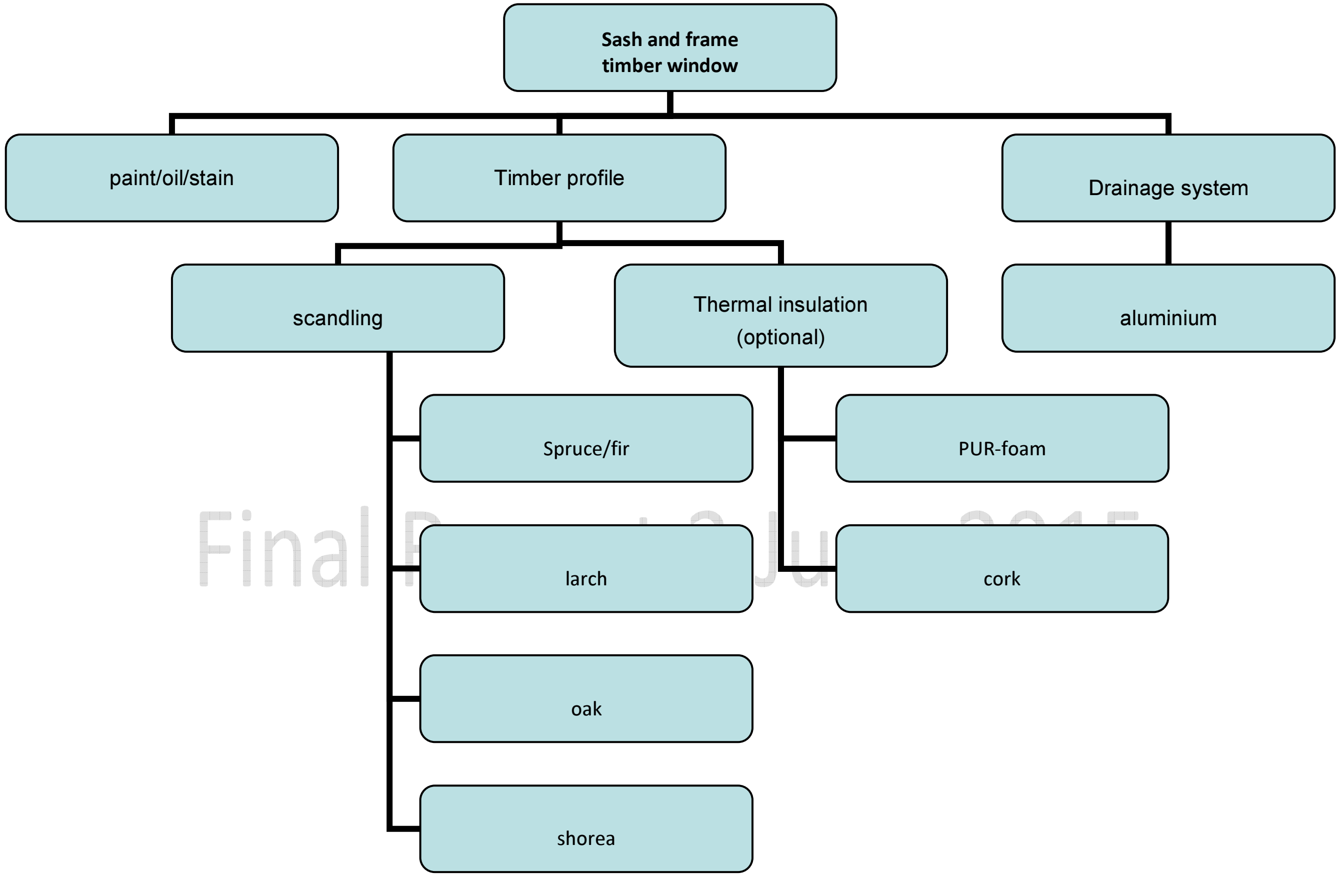


Figure 45: Different components of a plastic window

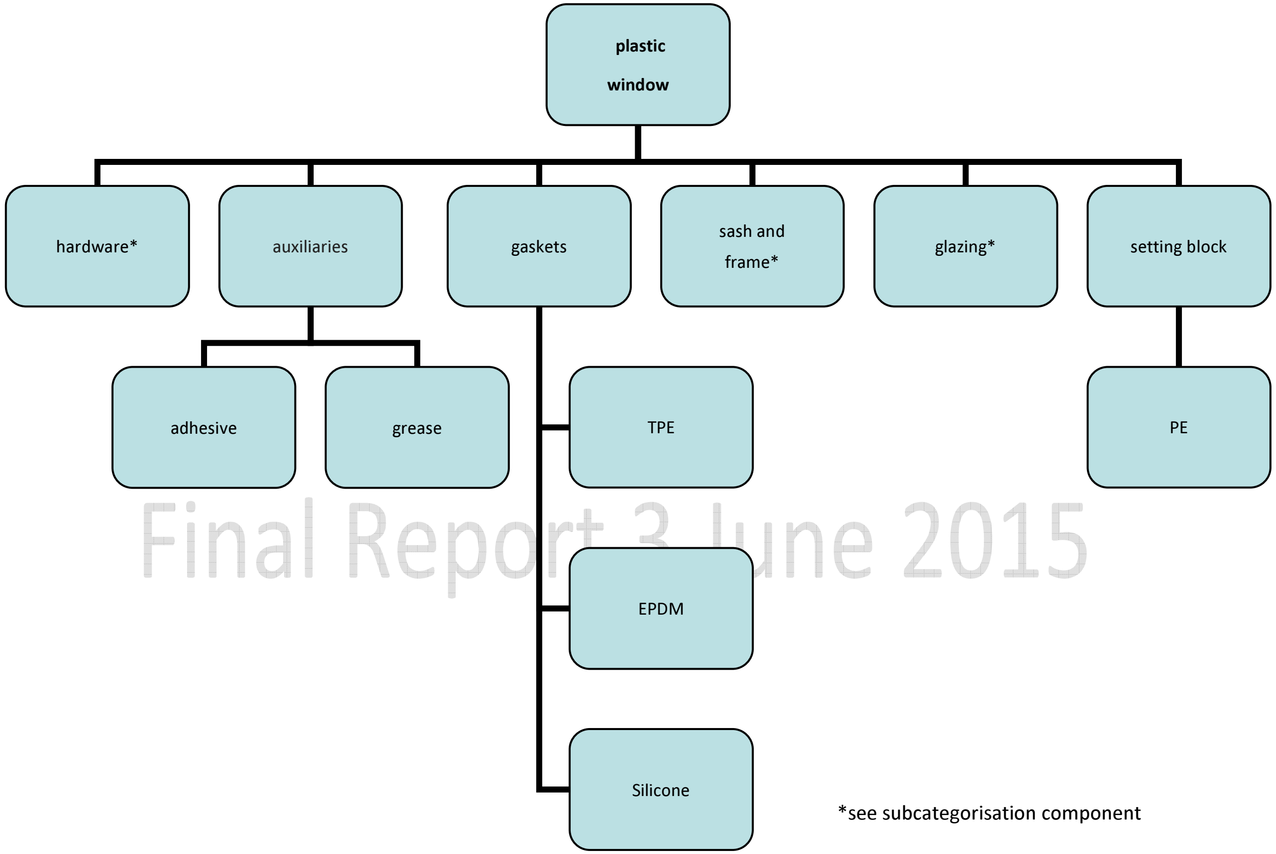


Figure 46: Different components of the sash/frame combination of a plastic window

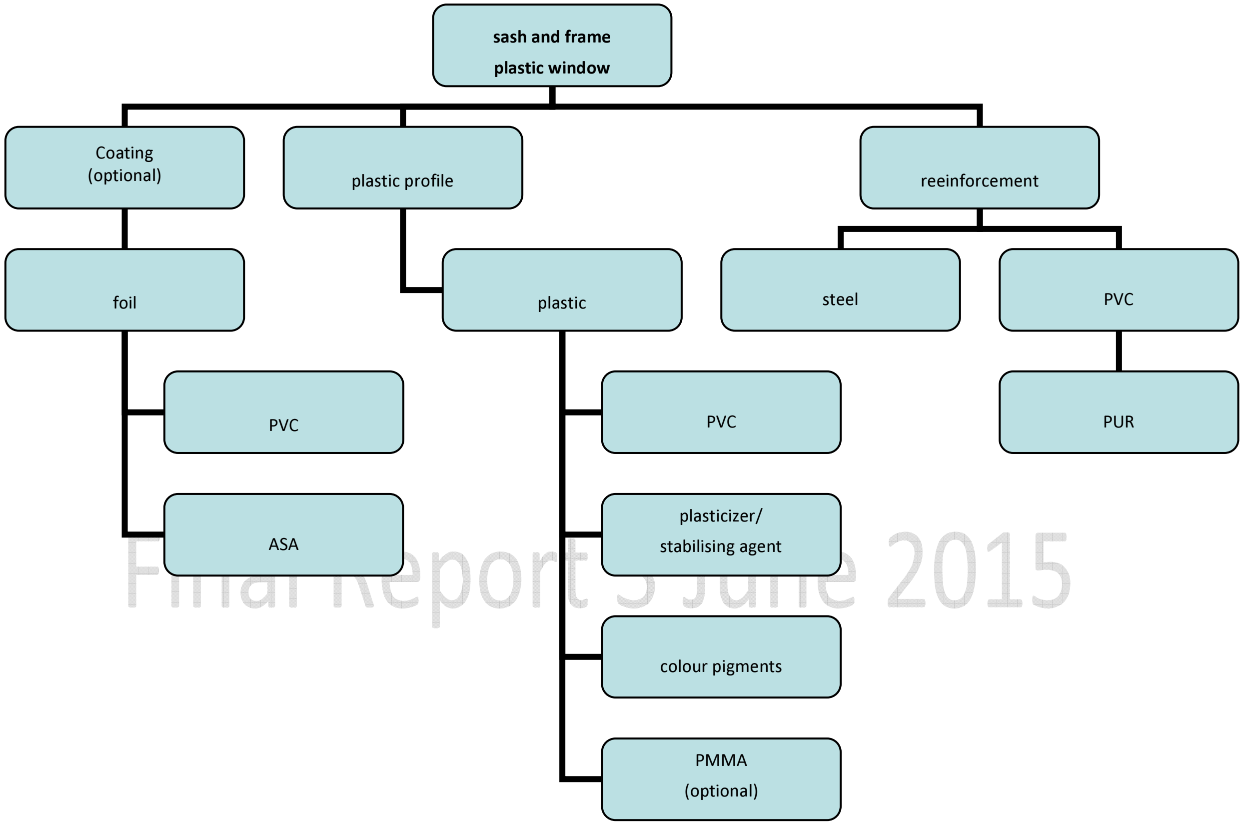

sash and frame
plastic window
Coating
(optional)
plastic profile
reeinforcement
foil
plastic
steel
PVC
PVC
PUR
ASA
PVC
plasticizer/
stabilising agent
colour pigments
PMMA
(optional)

Figure 47: Different components of a metal window

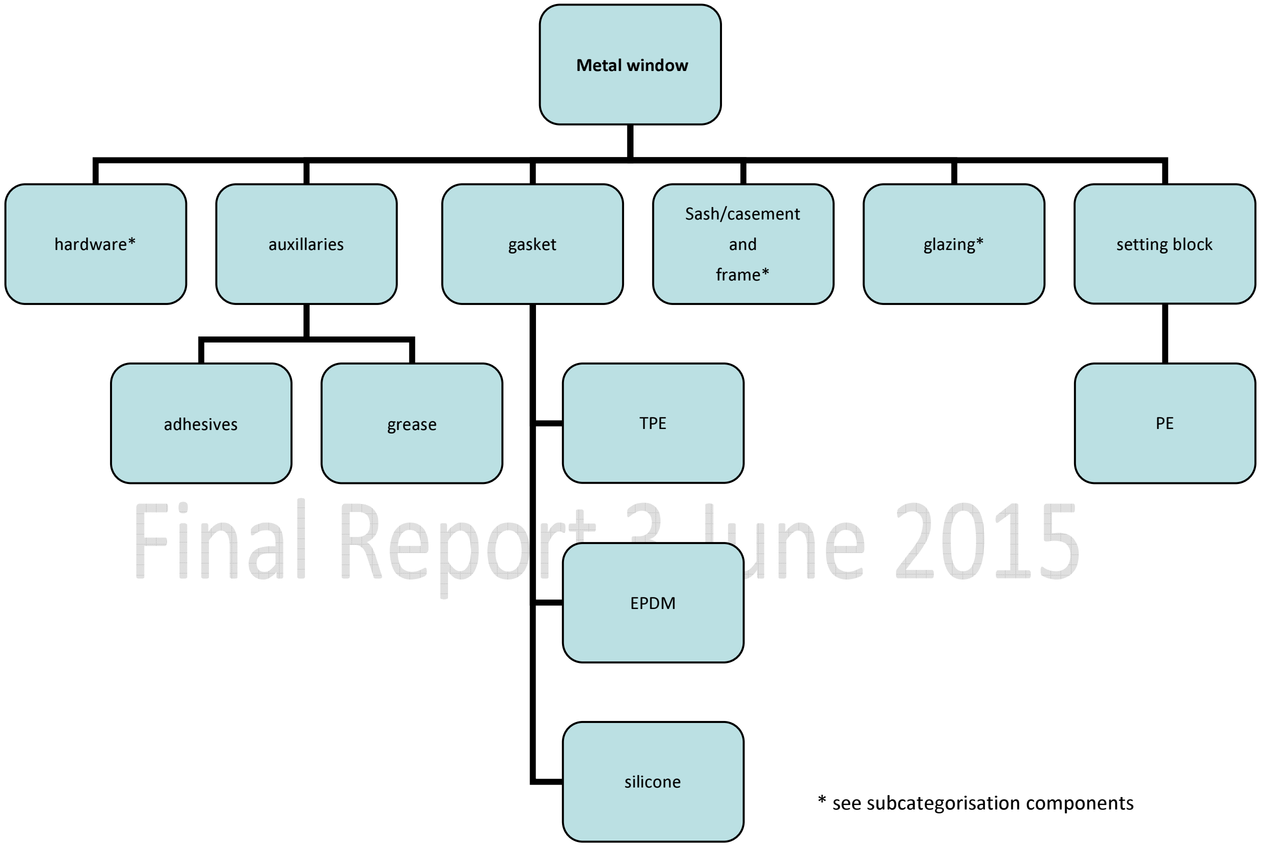
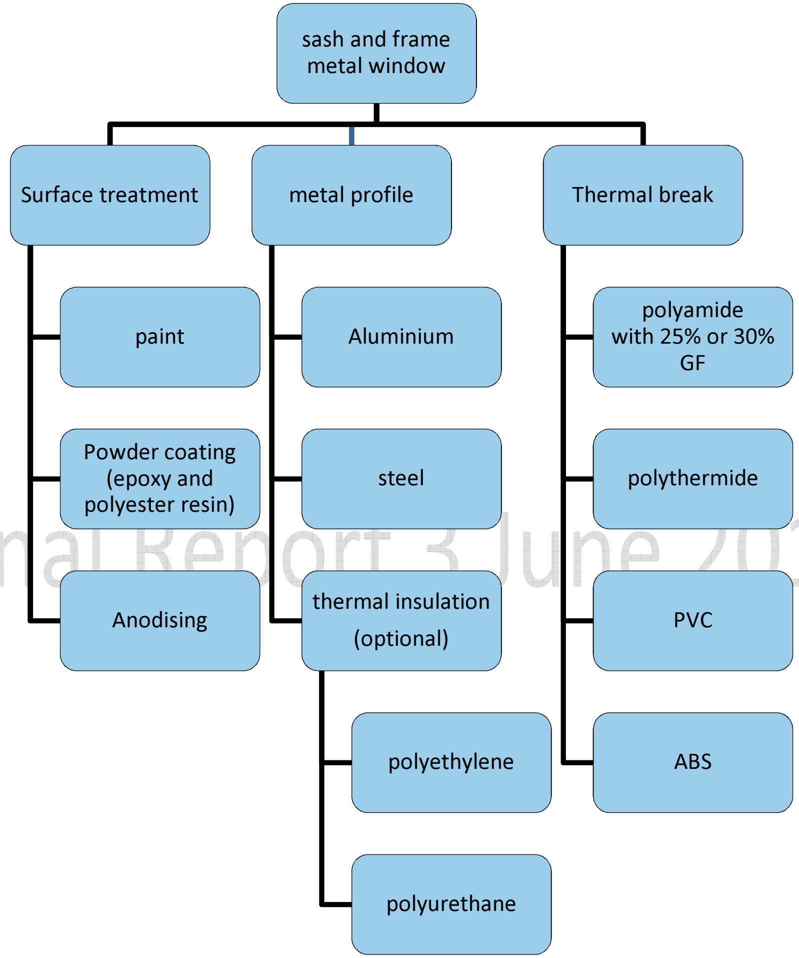


Figure 48: Different components of the sash/frame combination of a metal window



4.2.2. PRODUCT WEIGHTS

→ **Glazing**

The weight of the glazing is mainly influenced by the thickness of the glass panes. With a density of ρ = 2500 kg/m^3 the area related weight of a single pane is 2.5 kg/m^2 per mm glass thickness. For a double IGU using two 4 mm single panes the weight of the IGU can be calculated with 20 kg/m^2; for a triple glazing with 3x4 mm panes the weight is 30 kg/m^2. The additional weight of the edge spacers and the edge sealing and desiccant can be estimated with 0.5 kg/m^2 for a double IGU and with 1 kg/m2 for a triple IGU.

→ **PVC window**

The different main components used for the production of PVC window are having the following masses (indicative values).

Table 22 Components of PVC windows

Component	Mass
Glazing	2.5 kg/(m^2 mm)
Profile (sash and frame combination)	3 kg/m
Reinforcement (steel)	2.4 kg/m
Glazing bead profile (with coextruded gasket)	0.2 kg/m
Gasket	0.1 kg/m
Hardware (for a reference window 1.23 m x 1.48 m)	2.5 kg

Formulation of the PVC profiles: [19]

- 82.0 mass % PVC
- 6.5 mass % Filler (chalk)
- 4.9 mass % Impact-resistance modifiers
- 3.3 mass % Calcium/zinc stabilisers
- 3.3 mass % Titanium oxide (TiO2) pigment

→ **Timber window**

The different main components used for the production of timber window are having the following masses (indicative values).

Table 23 Components of timber windows

Component	Mass
Glazing	2.5 kg/(m^2 mm)
Timber profile **(depending on timber species and frame thickness)**	2-5 kg/m
Glazing bead profile	0.2 kg/m
Drainage Profile	0.4 kg/m
Gaskets	0.1 kg/m

[19] Source: EPD for PVC windows published by EPPA

→ **Aluminium window**

The different main components used for the production of Aluminium window are having the following masses (indicative values).

Table 24 Components of aluminium windows

Component	Mass indicative values
Glazing	2.5 kg/(m^2 mm)
Profile (sash and frame combination)	2,5 kg/m
Thermal break (PA6.6 with 25%GF)	0.09 kg/m
Glazing bead profile	0.4 kg/m
Gasket	0.1 kg/m
Hardware (for a reference window 1.23 m x 1.48 m)	1.5 kg

Aluminium Alloys: Mainly AA 6060 is being used.

Surface treatment:

- Powder Coating
- Anodised
- Wet coatings (no significant market share)

4.2.3. Bill of Materials

→ **Glazing**

For Float glass and IGU, the LCA assessment (see the following tables) was calculated by ift Rosenheim using Gabi software. All relevant background datasets for the production of Float, toughened glass and laminated glass are taken from the database of the software tool "GaBi 4.4".

The European electricity mix was used as the basis for energy consumed, with 2008 as the reference year. Raw materials were modelled using generic data and include average transport distance data. For the end of life scenario a collection rate and recycling rate of 90% in total were assumed. More details can be found in the ift EPD for flat glass products.

Table 25: LCA results for 1m² float per mm thickness

LCA results per m2 and 1 mm thickness	Manufacture	End of life
Primary energy non-renewable in MJ	44.3	-18.6
Primary energy renewable in MJ	0.95	-0.18
Global warming potential GWP 100 in kg CO_2 equiv.	2.67	-1.39
Ozone depletion potential (ODP) in kg R11 equiv.	1.84×10^{-8}	-3.65×10^{-9}
Acidification potential (AP) in kg SO_2 equiv.	0.023	-0.014
Eutrophication potential (EP) in kg PO_4^{3-} equiv.	2.52×10^{-3}	-0.001
Photochemical ozone creation potential (POCP) in kg C_2H_4 equiv.	1.37×10^{-3}	0.000
Abiotic resources depletion potential (elements) (ADP_{el}) in kg Sb equiv.	1.33×10^{-5}	-1.23×10^{-5}
Abiotic resources depletion potential	38.55	-14.01

(fossil) (ADP_{fos}) in kg Sb equiv.		
Water consumption in m^3	1.219	-0.36

Table 26: LCA results for 1m² triple IGU 4/x/4/x/4 with low e-coating on position 2 and 5

LCA results per m2	Manufacture	End of life
Primary energy non-renewable in MJ	574.7	-165.5
Primary energy renewable in MJ	26.7	-1.55
Global warming potential GWP 100 in kg CO_2 equiv.	44.7	-19.76
Ozone depletion potential (ODP) in kg R11 equiv.	4.42×10^{-7}	-4.45×10^{-8}
Acidification potential (AP) in kg SO_2 equiv.	0.36	-0.15
Eutrophication potential (EP) in kg PO_4^{3-} equiv.	0.040	-0.014
Photochemical ozone creation potential (POCP) in kg C_2H_4 equiv.	0.020	-0.004
Abiotic resources depletion potential (elements) (ADP_{el}) in kg Sb equiv.	2.8×10^{-4}	-1.2×10^{-5}
Abiotic resources depletion potential (fossil) (ADP_{fos}) in kg Sb equiv.	480.9	-120.6
Water consumption in m^3	33.0	--5.12

Table 27: LCA results for 1m² double IGU 4/x/4 with low e-coating on position 2 or 3

LCA results per m2	Manufacture	End of life
Primary energy non-renewable in MJ	397.5	-91.1
Primary energy renewable in MJ	22.9	-0.83
Global warming potential GWP 100 in kg CO_2 equiv.	34.02	-14.2
Ozone depletion potential (ODP) in kg R11 equiv.	3.68×10^{-7}	-2.99×10^{-8}
Acidification potential (AP) in kg SO_2 equiv.	0.268	-0.094
Eutrophication potential (EP) in kg PO_4^{3-} equiv.	0.030	-0.010
Photochemical ozone creation potential (POCP) in kg C_2H_4 equiv.	0.015	-0.004
Abiotic resources depletion potential (elements) (ADP_{el}) in kg Sb equiv.	2.27×10^{-4}	-6.12×10^{-5}
Abiotic resources depletion potential (fossil) (ADP_{fos}) in kg Sb equiv.	326.7	--64.56
Water consumption in m^3	28.1	-3.68

Note:

Glass for Europe published also two independent reports[20] stating results of the float glass LCA. These two reports provide different sets of results, which can be reasonably explained by the fact that different upstream data and software's were used.

Glass for Europe gives furthermore the following remarks and recommendations when comparing these LCAs:

> "The outcomes delivered by both consultants in charge of the float glass life-cycle analysis resulted in two sets of data with inherent variances in the figures.
>
> Gate-to-gate data provided by Glass for Europe to the consultants are the same, therefore variances are inherited from the use of different databases and subsequent choice of data sets, as well as the different modelling applied by the consultants. Along with LCA experts, Glass for Europe believes that variances up to 20% remain acceptable so long that they are justifiable for the reasons explained above. This illustrates that when publishing or comparing LCA figures, there is no unique absolute value as such. The figures have to be appreciated within the confidence levels of LCA works.
>
> Within this Glass for Europe work on clear float glass, variances are generally low except for a few indicators/data of less relevance and limited impact in the case of glass manufacturing. Glass for Europe is comfortable with the overall convergence of the results and believes that it reinforces the validity of the work. This work is the most comprehensive, in-depth and accurate life-cycle assessment made on clear float glass at European level."

→ **Hardware**

The data presented is based on the EPD for window hardware published by the Fachverband Schloss- und Beschlagindustrie e.V. The data represents a typical hardware for tilt- and turn windows with a dimension of 1.23 x 1.48 m.

The EPD distinguishes between hardware for PVC and timber windows or Aluminium windows.

Table 28: materials and corresponding masses for a tilt and turn hardware

	Tilt and turn PVC or timber window		Tilt and turn Aluminium window	
Material	Mass in kg	%	Mass in kg	%
Steel (galvanised)	2.045	91	0.286	19
Zinc die cast	0.169	8	0.830	57
PA 66 with 25%GF	0.015	1	0.020	1
Stainless steel	0.018	1	0.012	1
Aluminium strand cast			0.282	19
Brass die cast			0.039	3
Total	2.247	100	1.469	100

Table 29: LCA results for a tilt and turn hardware for a PVC or timber window

LCA results	Manufacture	Transport	End of life
Primary energy non-renewable in MJ	94.71	1.60	-38.26
Primary energy renewable in MJ	5.13	1.7×10^{-3}	-1.36
Global warming potential GWP 100 in kg CO_2 equiv.	6.577	0.115	-2.508
Ozone depletion potential (ODP) in kg R11 equiv.	3.1×10^{-7}	1.9×10^{-10}	--2.6×10^{-10}

[20] http://www.glassforeurope.com/en/issues/life-cycle-analysis.php#4

Acidification potential (AP) in kg SO_2 equiv.	1.9×10^{-2}	4.4×10^{-4}	-9.9×10^{-3}
Eutrophication potential (EP) in kg PO_4^{3-} equiv.	1.8×10^{-3}	7.3×10^{-5}	-9.9×10^{-4}
Photochemical ozone creation potential (POCP) in kg C_2H_4 equiv.	2.4×10^{-3}	4.4×10^{-5}	-1.3×10^{-3}

Table 30: LCA results for a tilt and turn hardware for an Aluminium window

LCA result	Manufacture	Transport	End of life
Primary energy non-renewable in MJ	131.1	0.88	-78.12
Primary energy renewable in MJ	20.85	9.6×10^{-4}	-15.51
Global warming potential GWP 100 in kg CO_2 equiv.	9.146	0.063	-5.562
Ozone depletion potential (ODP) in kg R11 equiv.	9.5×10^{-7}	1.0×10^{-10}	$--5.7 \times 10^{-7}$
Acidification potential (AP) in kg SO_2 equiv.	3.7×10^{-2}	2.4×10^{-4}	-2.7×10^{-2}
Eutrophication potential (EP) in kg PO_4^{3-} equiv.	2.0×10^{-3}	4.0×10^{-5}	-1.2×10^{-3}
Photochemical ozone creation potential (POCP) in kg C_2H_4 equiv.	3.2×10^{-3}	2.4×10^{-5}	-2.4×10^{-3}

→ **Timber window**

Based on the masses (indicative values) for the main components presented above, the mass of a complete window (1.23 m x 1.48 m) is estimated.

Table 31: Main materials and corresponding masses for a timber window

Component	Main material	Mass in kg
Transparent element (4/16/4)	Glass	25
Profiles	Wood	20
Drainage profile	Anodized or powder coated aluminium	0.5
Surface coating	paint	0.5
Gaskets	EPDM	1
Sealant	Silicone	0.5
Hardware	Steel (so also Table 28)	2.5

For the production of a typical timber window approx. 16 kWh electrical energy is used[21].

[21] Source: Final report: "EPDs for transparent construction elements", **ift** Rosenheim

→ **PVC window**

Based on the masses (indicative values) for the main components presented above, the mass of a complete window (1.23 m x 1.48 m) is estimated.

Table 32: Main materials and corresponding masses for a PVC window

Component	Main material	Mass in kg
Transparent element (4/16/4)	Glass	25
Profiles	PVC	16
Reinforcement	Zinc coated steel sheets	15
Gaskets	EPDM	1.5
Hardware	Steel (so also Table 28)	2.5
Small components (Screws)	Steel	0.1

For the production of a typical PVC window approx. 2 kWh electrical energy is used[22].

→ **Aluminium window**

Based on the masses (indicative values) for the main components presented above, the mass of a complete window (1.23 m x 1.48 m) is estimated.

Table 33: Main materials and corresponding masses for an Aluminium window

Component	Main material	Mass in kg
Transparent element (4/16/4)	Glass	25
Profiles	Anodized or powder coated aluminium	14
Thermal break	PA 6.6 with 25% glass fibre	2
Gaskets	EPDM	1.5
Hardware	Steel (so also Table 28)	1.5

For the production of a typical aluminium window approx. 1.4 kWh electrical energy is used[23]

→ **Roof window**

According the EPDs for various roof windows, the bill of materials is as shown below.

Table 34: Main materials and corresponding masses for a Roof window

Type / component	CFP100100 0073Q + ISD0110 or ISD0010	Type / component	CFP100100 0073Q + ISD0100 or ISD0000
	(kg)		(kg)
Insulating Glass Unit	21.8	Insulating Glass Unit	21.8
PVC	16.6	PVC	16.6
PC	7.8	PMMA	8.7

[22] Source: Final report: "EPDs for transparent construction elements", **ift** Rosenheim

[23] Source: Final report: "EPDs for transparent construction elements", **ift** Rosenheim

Other plastic	1.1	Other plastic	1.1
Metals	0.1	Metals	0.1
Total	47.5	Total	48.4

→ Solar shading device / shutter

The most popular solar shading device is a (PVC) roller shutter. The material input is limited to 3 kg per m^2 window[24].

4.2.4. HAZARDOUS SUBSTANCES USED IN PRODUCTION

→ Wood preservation

The objective of wood preservation is to (artificially) increase the resistance of products from wood species that are not sufficiently resistant to attack by especially fungi (but also insects, bacteria and other), by impregnating the wood with a wood preservative. Preservation is therefore only necessary if the application contains a real risk of infestation which means certain conditions (the right combination of moisture, oxygen , nutrients and temperature) need to be favourable for the organisms responsible for rot.

The preservation must therefore be adapted to the wood type and application conditions. For wooden windows the use of preservation is rather limited. According to the Dutch window manufacturers association (NVBT) some 30 years ago manufacturers of wooden windows frames started to apply bifluoride compounds (NL: improsoleren) but application of these compounds have reduced and is rarely applied nowadays. The most common technique for wood preservation nowadays is applying capsules of boric acid.

Besides wood preservation by diffusion or impregnation with chemical compounds other forms of prevention must be mentioned, such as good design (avoid permanent contact with moist, allow to ventilate and dry) and alternatives to (tropical) hard wood such as chemically modified soft wood (e.g. heat treated, acetylation, methylation).

In other application areas (wood in permanent contact with water, or moist, such as in the civil engineering sectors) wood preservation on the basis of: water soluble metal oxide compounds, based on copper, chromium and/or boric acid, and/or arsenic, with or without biocides, creosote-oil and water soluble bi-fluorides may still be applied, but the demands for such applications are very different to that of windows.

→ Aluminium surface (pre)treatment[25]

Aluminium window frames are often coated or anodised to provide colour and improved weather resistance. Such surface coatings require pre-treatment which may use Cr6+ compounds. Cr6+ is a hazardous substance.

Cr6+ pre-treatment is used for a very long time by the aluminium coaters and allegedly the process is well controlled, meaning that only very small quantities are reacting on the surface. Almost all Cr6+ are then converted in Cr3+ on the surface which is then further coated and baked in a furnace. Hence, the coated Al profiles are not toxic and do not release any Cr6+ ions / substances.

There are alternatives under development for some time, but their adoption is mainly triggered by the REACH legislation which will forbid the use of Cr6+ by Sept 2017 except if there is a specific request for authorisation submitted by March 2016 and accepted. At this stage it is unclear whether applications for authorization will be submitted for Al pre-treatment.

The alternatives surface treatment methods, are based on: oxides of Ti, Zr, Ce, pre-adonisation, silanes, and some additional precautions need to be taken for the alternatives solutions and coating lines may need to be modified

It is most likely that the Cr6+ pre-treatment lines in EU will switch to alternatives treatments in the next 2-3 years.

[24] Source: http://www.fenster-sell.de/rolladen/ra.html

[25] The information in this paragraph is based on comments from the European Aluminium Association (EAA)

→ **PVC windows**[26]

For PVC windows the use of lead-based stabilisers declined by 81% in the EU-27 compared to 2007, progressing towards the target of completing their substitution by the end of 2015. The use of phthalates and other plasticisers is not relevant for rigid PVC products such as windows. Restricting the presence of lead in PVC windows would severely hamper the potential for recycling into new PVC windows, unless an exemption for recyclates to contain up to 1% lead is introduced as well.

Cadmium has been used in semi-rigid and flexible foil for products such as roofing membranes and in rigid applications for outdoor use such as window profiles. In Europe, they have been replaced by barium/zinc stabilizers in foils. The EU Directive 91/338 still allowed the use of cadmium stabilisers in window profile and roofing membranes but the Voluntary Agreement of the PVC Industry signed in 2000 resulted in discontinuation of use of cadmium stabilizers by all its members as from 2001. Directive 91/338 was included in Annex XVII of the REACH chemical Regulation (Restrictions) when REACH entered into force. The provisions regarding cadmium were amended in 2011 by Regulation 494/2011, which extended the 0.01 % cadmium limit to all PVC articles, but contains derogation for most rigid PVC construction products containing recovered PVC, where cadmium levels may be up to 0.1 % weight. This derogation will be reviewed by end 2017[27].

4.3. Packing Materials

With the exception of roof windows, which are almost exclusively delivered to the customer in an outer packing, windows will be delivered with few if any packaging or in multi-use racks owned by the manufacturer.

Figure 49 Packaging of windows - examples (Source: Velux)

Roof windows packed special packaging concept for roof windows Source: VELUX

According information submitted by VELUX the materials used for the packaging for a roof window with dimensions of 1140 mm x1398 mm are as follows:

- Cardboard: 3,695 kg
- PE film: 0,046 kg
- Labels: 0,014 kg
- Tape: 0,006 kg
- EPS 0,299 kg
- Staples 0,006 kg
- Hot melt 0,029 kg

[26] The information in this paragraph is based on comments from EPPA

[27] Source: http://www.pvc.org/en/p/cadmium-stabilisers

4.4. Actual Means of Transport

For the production of a window the following main components are assembled by the window manufacturer:

- glazing
- profiles (sash and frame)
- hardware
- gaskets

Currently there is no published data available to analyse the mean transport distance for the different components. Therefore the following distances are estimated considering the locations of the production plants of the respective components in Europe.

It has to be kept in mind that the distances in Europe vary strongly. There are large distances in large countries (e.g. France) and small distances in small countries (e.g. Belgium). Additionally the individual locations of the production plants of the respective components in Europe have to be considered.

The stakeholders were kindly asked to check the data and to give further information if necessary.

Table 35: Means of transport and distances (indicative values)

	Component	Average distance in km	Means of transport
1	Glazing (IGU, single glass)	Approx. 200	Truck 7 t capacity 85% use of capacity
2	Hardware	Approx. 500 - 1000	Truck 25 t capacity 85% use of capacity
3a	Plastic Profile* (frame and sash)	Approx. 300	Truck 25 t capacity 85% use of capacity
3b	Metal Profile (frame and sash)	No information available	No information available
4	Gaskets	Approx. 500-1000	Truck 25 t capacity 85% use of capacity

.* according to information submitted by EPPA

So far it is expected (based on existing LCA) that the transport of the components to the window manufacturer has no significant impact on the LCA of windows.

4.5. End of Life

In-house recycling is a common procedure for the production waste of PVC and metal profiles. During this process, the production waste generated in converting machines is comminuted and then immediately recovered. As these materials are rather pure, have not been subject to aging and may be reused in general without further transport or processing effort, the in-house recycling is not considered in the following.

4.5.1. Construction and Demolition Waste (CDW)[28]

Construction and demolition waste is one of the heaviest and most voluminous waste streams generated in the EU. It accounts for approximately 25% - 30% of all waste generated in the EU and consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil, many of which can be recycled.

Construction and demolition waste has been identified as a priority waste stream by the European Union. There is a high potential for recycling and re-use of CDW, since some of its components have a high resource value. In particular, there is a re-use market for aggregates derived from CDW waste in roads, drainage and other construction projects.

[28] Cited from: http://ec.europa.eu/environment/waste/construction_demolition.htm

However, the level of recycling and re-use of CDW waste varies greatly (between less than 10% and over 90%) across the Union. In some Member States, this waste stream is to a large extent disposed of, using up valuable space in landfills.

One of the objectives of the Waste Framework Directive (2008/98/EC) (WFD) is to provide a framework for moving towards a European recycling society with a high level of resource efficiency. In particular, Art. 11.2 stipulates that "Member States shall take the necessary measures designed to achieve that by 2020 a minimum of 70% (by weight) of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the List of Wastes shall be prepared for re-use, recycled or undergo other material recovery (including backfilling operations using waste to substitute other materials).

The WFD introduces a European Waste Hierarchy, which refers to the 5 steps included in the article 4:

- **Prevention** - preventing and reducing waste generation.
- **Reuse and preparation for reuse** - giving the products a second life before they become waste.
- **Recycle** - any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes composting and it does not include incineration.
- **Recovery** - some waste incineration based on a political non-scientific formula that upgrades the less inefficient incinerators.
- **Disposal** - processes to dispose of waste (landfill, incineration, pyrolysis, gasification etc.)

This European Waste Hierarchy is legally binding except in cases that may require specific waste streams.

The European Commission has funded a report[29] called "Construction and demolition waste management practices and their economic impacts". Basic aim of the project was to investigate the quantities of construction and demolition waste (CDW) among the European Union as well as the measures, which each Member States has taken to improve the re-use and the recycling of this waste stream. The report describes the best practices in this field as well as the economics of the CDW reuse and recycling. It shows, that in most member states, there are mostly only aggregated figures, which do not differentiate between glass, plastic, metal and wood. The quotas for recycling differ widely, but in general items with economic value (mostly metals) are removed before or after the demolition of buildings. Data for CDW in the Netherlands shows that metal is recycled to 100%, plastic only to 5% (no figures for glass were available).

4.5.2. Reuse of windows

As stated below, windows have a product life of 25 to 50 years or more. With very few exceptions, which shall be disregarded in the following, there is no re-use of complete windows as they are either obsolete from a technical point of view and/or they are damaged at removal.

4.5.3. Recycling of window materials

Waste at the end-of-life of windows is a predictable waste stream of glass, wood, plastic (UPVC[30]), metal and gaskets or sealants.

Separating these materials can be achieved either at source or at the station where it is taken. In some member states there are already established networks of Waste companies who can separate these materials sending them to their respective recycling partners downstream.

Recovery and Recycling are to be understood to be according the definitions in the Waste Framework Directive 2008/98/EC.

[29] http://ec.europa.eu/environment/waste/studies/cdw/cdw_report.htm

[30] unplasticised PolyVinyl Chloride

→ **Glass**[31]

The situation regarding recycling of flat glass from building CDW is confusing at best. In short, Glass for Europe states that end-of-life building glass is almost never recycled into new glass products, whereas a German study claims that almost all glass disposed is also recycled.

A part of the confusion is caused by system boundaries and definitions: Glass-for-Europe applies a very strict interpretation of recycling: the waste product is recycled into a similar product (float glass becomes float glass) According GfE this does not occur on significant scale.

The German BV Glass claims that virtually 2/3 glass collected from renovation and demolition is used again, either as container glass, glass wool insulation or glass beads for technical use. This is a much broader definition of recycling, and presumably includes recovery by backfilling.

The study lot 32 on Windows tries to be in line with existing community legislation and therefore should use the Waste Framework Directive 2008/98/EC definition of recycling and recovery:

'recycling' means any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations[32];

'recovery' means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy. Annex II sets out a non-exhaustive list of recovery operations;

This means that the actual window recycling percentage includes recycling into container glass and glass wool, but not glass beads for engineering purposes, insofar these can be regarded as backfilling operations (which is covered under 'recovery'). Disposal[33] is not recovery but e.g. landfill.

The more elaborate explanation of both positions is presented below:

The position paper on recycling Glass for Europe states that despite its recyclability, end-of-life building glass is almost never recycled into new glass products. Instead it is often crushed together with other building materials and put into landfills or recovered.

Under the Waste Framework Directive, the Commission Regulation 1179/2012 establishing criteria determining when glass cullet ceases to be waste (end-of-waste) was published in December 2012. According to this Regulation end-of-waste status can be attributed to flat glass materials. This is recognition of the existing opportunity for glass materials to be recycled and should be seen as facilitating recycling. The flat glass industry welcomes this Regulation, but believes that as an isolated measure it is not enough to promote collection and recycling of Construction & Demolition glass.

Building glass currently has a low market value because there is a lack of properly organised collection and recycling systems to generate what would be a valuable glass-making raw material.
One of the complexities that need to be taken into account is the variety of building glass. In general, recovered building glass can be grouped into three categories:

1) Glazing from large tertiary building (facades);
2) Glazing from residential collective buildings and individual houses' windows;
3) Glass used for interior applications (balustrades, glass walls, mirrors, etc.).

Also, the cullet from building glass differs from that of bottles, so that it needs to be collected separately. Building glass cullet that cannot be recycled technically and cost effectively in the flat glass sector, could be recycled in other sectors of the glass industries, such as in the container and fibre glass sectors.

[31] Position paper on recycling - Glass for Europe - June 2013

[32] Backfilling operations are not defined in the Directive itself, but in the Commission Decision of November 18, 2011 establishing rules and calculation methods for verifying compliance with the targets set in Article 11(2) of the Directive, as being "a recovery operation where suitable waste is used for reclamation purposes in excavated areas or for engineering purposes in landscaping and where the waste is a sunstitute for nonwaste materials".

[33] According 2008/98/EC Waste Framework Directive 'disposal' means any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy. Annex I sets out a non-exhaustive list of disposal operations;

Figure 50 End-of-life activities for glass of windows

Dismantling of the windows. Stacking the window in skip After recycling

The German association for windows and facades VFF drafted a survey to ask their German members about the situation in Germany. The result is shown in the following figure.

Figure 51 Result of VFF survey – Recycling of flat glass from old windows

Result of VFF Survey
Recycling of flat glass from old windows

VFF
Verband Fenster + Fassade

- 76 companies from 109 participants are replacing old windows (~ 70%)
- From these 76 companies
  - 64 % dispose the window completely
  - 31 % dispose the frame and glass units separately
  - 4 % dispose the frame, flat glass and edge seal separately
  - 1 % send the window to waste disposal
- 47 % use the glass suppliers for recycling of the glass
- 40 % have no fixed recycling/disposal partner
- About 50 % of the companies count the mass of the material
- Average flat glass per company is 59 t
- Average of frame recycling per company is
  - Metal profiles 8 t
  - PVC profiles 37 t
  - Timber profiles 32 t

According comments received by Glass for Europe [34] the following percentages can be applied to the following operations:

- Reused: 0%
- Recycled: 10%
- Recovered: 25%
- Not recovered: 0%
- Landfilled: 65%

BIO by Deloitte is conducting an economic study for Glass for Europe, on building glass collection & recycling opportunities in Europe. The scope of the study is to shed light on today's situation, estimates of end-of-life quantities, existing routes and schemes throughout the EU. The study should have been finalized by the end of 2014, but at the time of writing results were not yet available.

Flat glass manufacturers are willing to collaborate in the promotion and development of effective collection and recycling schemes for end-of-life building flat glass.

Glass for Europe takes the view that the current targets on building waste materials do not provide enough ambition to recycle glass because glass represents less than 5% of the C&D waste. Therefore Glass for Europe is of the opinion that, when revising the targets on C&D waste[35], individual targets on specific types of waste (such as glass) should be set, in line with the global target on C&D waste. This should lead to increased dismantling, sorting and collection of glazing and/or windows from buildings. Otherwise, provisions to dismantle and sort the glass should be made mandatory.

[34] Dated 28 November 2015, regarding TASK 5.

[35] The Directive foresees, under article 11.4, these targets to be examined and reinforced, if necessary, by 31 December 2014.

Audits before demolition or renovation of tertiary buildings are another measure that Glass for Europe believes could significantly boost recycling. Audits should lead to recommendations and obligations as to the sorting and recycling of glass material per type of glass (e.g. clear, laminated, reinforced, enamelled, etc.), where this is feasible and cost effective. These type of audits are already required in France[36] and in the United Kingdom as part of the granting of demolition permits.

BV Glas / BF

According to figures which the German associations BV Glas and BF have collected together with Saint-Gobain Glass Germany for a study commissioned by Glass for Europe, the following amounts of glass out of windows (end-of-life) accrued in Germany in 2013 (in tons):

Table 36 Glass recovery according BV Glas

	from renovation	from demolition	Sum Σ
residential buildings	218.000	26.000	244.000
tertiary buildings	127.000	74.000	201.000
Sum Σ	345.000	100.000	445.000

According to BV Glas, German container glass companies used approx. 300.000 t of flat glass cullet in their production in 2012. The origin of this cullet out of flat glass can be traced because the recycling enterprises sell them to the container glass producers as a defined product. Recycling enterprises confirmed this in a meeting with BV Glas and BF. According to a survey of BV Glas (among whose members there are also automotive glass producers), approx. 40.000 out of these 300.000 tons come from automotive glass. A certain part of the remaining 260.000 t could come from the pre-consumer- and not from the post-consumer-sector. This part would have to be subtracted to find out the amount of flat glass, which goes "end-of-life" into recycling as container glass. However, this part cannot be very large: In Germany, approx. 1.760.000 t of float glass were produced in 2012. Taking into account imports and exports, this yields approx. 1.500.000 t which were put on the market in Germany in 2012. The quantity of glass (waste, offcuts) going into recycling while the glass is finished (pre-consumer) is without doubt clearly less than 10 % of this (150.000 t). To a very high percentage, this quantity goes back into flat glass production; only in the case of colourings / coatings / layers etc. the recycled material is often not pure enough for the production of flat glass, so this material goes to the container glass production or to the production of insulating material.

In sum, the recycling-rate of pre-consumer glass wastes in Germany is close to 100 %. The cullet which is used for production of insulating material can be estimated to 40.000 tons (recycling rate glass wool 40 %; production of glass wool 212.000 t in 2012; assumption: 20 % cullet = flat glass)

To summarize, estimated conservatively, 300.000 t of end-of-life flat glass cullet are recycled producing container glass, insulating material or glass beads for technical use, which means 67 % resp. out of the total 445.000 t.

Typically, these quantities come from renovation, whereas the 100.000 t resulting from demolition are typically disposed of as construction waste (rubble), which is crushed and used in road construction. In this way, it still serves to spare other raw materials.

Therefore the recycling rate of building glass is not zero (because recycling into container glass and glass wool is also recycling), but neither 67%, as this includes presumably includes backfilling operations which is recovery, not recycling.

Therefore, this study assumes the GfE suggested percentages of window waste treatment scenarios.

→ Plastic

Plastic for window frames is UPVC[37], which has been regarded as a difficult material to recycle. There are now companies in some countries (for example Netherlands, France, Great Britain and Germany), who can do this, completing the loop on recycling glazing waste. It must be kept in mind, that UPVC is a comparatively new material, so that – depending on

[36] French decret 2011-610 du 31 mai 2011 relatif au "diagnostic portant sur la gestion des déchets issus de la démolition de categories de bâtiments

[37] unplasticised PolyVinyl Chloride

the time of market entrance, the different increase in market share and the usual use-phase – in many member states up to now only few UPVC window frames have entered the waste stream and a due to the comparatively low market value of scrap UPVC recycling business is just emerging.

UPVC windows have handles, hinges and locks as well as steel strengthening bars within them which mean they need to be destructed, separating the metal components from the plastic.

Recycled PVC material obtained from used windows is used to manufacture proprietary profiles. These profiles can contain more than 0.1% lead compounds. These are treated as SVHC (Substances of Very High Concern) in accordance with REACH.

Regarding the stabilizers EPPA informed, that lead stearate will be fully removed by CaZn as far as European system houses are concerned.

The European PVC industry stresses that PVC window profiles have increased market share very fast over the past 30 years. This means that the amount of profile waste now arising is much lower than the amount of profiles put on the market.

Unfortunately there is no hard data about the amount of profiles waste that is currently becoming available in the EU. For PVC products in general, the amount of available waste at EU level is estimated around 2.5 Mt annually, compared to 5-6 Mt of PVC products put on the market.

There is a complex discussion going on about the attribution of the recycling benefits when calculating resources use: to the product becoming waste and being recycled (past) or to the new product incorporating recycled material (future).

According the European PVC industry EN 15804 (EPD) offers several options. The Product Environmental Footprint system currently in development may attribute 1/2 to the past and 1/2 to the future.

The depositing of untreated plastics and other organic materials is out-dated and is no longer permissible in some European countries. In Germany, a regulation in the form of a ban on depositing organic waste such as wood, paper, and plastics has been in effect since 2005 (source: DepV – Landfill Ordinance, Technical Guidelines – Municipal Waste). In Austria, the topic was dealt with in the same way through the Landfill Ordinance of 2008 (“everything about PVC” www.renolit.com).

The concern for PVC in landfills is that additives including plasticisers and metal-based stabilisers will leach from the PVC into the environment. The recognised potential is greatest for flexible PVC products, such as floor coverings, that carry the greater amount of additives by weight. Research suggests that leaching of chemicals of concern in landfill settings does occur but in most cases is minimal. In those cases where releases of chemicals were increased, high temperatures and acidic conditions were required (www.greenspec.co.uk).

PVC Waste Management Sector Projects

EPPA (European PVC Window Profile and Related Building Products Association[38]) operates window collection and recycling schemes by strategic partnerships. It reported a recycled tonnage of 198 ktons of window profiles and related profiles in 2012 and 192,4 kton in 2013. This includes recycling under Recovinyl and Rewindo, two key examples in Germany and the UK: in Germany, Rewindo recycled 100,725 tonnes of windows and profiles in 2012; in the UK, Recovinyl registered 25,480 tonnes of PVC windows and profiles recycled.

The total amount of 192.4 kT has to be referred to the production of about 1,400 kT of PVC window profiles in Europe. These values result in a recycling rate of (192/1400) of 13.7%. Not included are roller shutters out of PVC. The total amount of PVC windows and roller shutters is estimated to be about 240 kT.

According EPPA this means that some 2.5 million of window frames were recycled only in Germany and the UK (source: vinylplus Progress Report 2013 www.vinylplus.eu). Applying this value to combined DE + UK 25 million residential window unit sales (based on calculation model) gives a maximum recycling rate of approximately 10%. The difference with the 13.7% calculated on basis of kT may be caused by a difference in recalculating the million m2 window area to average window units (differences in average window dimensions and window-to-floor ratio, etc.). Nonetheless the values seem in rather good agreement (no order of magnitude difference).

[38] www.eppa-profiles.org

Figure 52 PVC recycling (various sectors, 2012-2013

PROJECT	TYPE OF PVC	TONNAGE RECYCLED IN 2012	TONNAGE RECYCLED IN 2013
IVK/EPCoat (incl. Recovinyl)	Coated fabrics	6,364*	7,663*
EPFLOOR	Flooring	3,420*	3,618*
EPPA (incl. Recovinyl)	Window profiles & profile related PVC	198,085	192,419
ESWA – ROOFCOLLECT and Recovinyl	Flexible PVC	21,418 tons which consist of:	77,319 tons which consist of:
ESWA – ROOFCOLLECT	Flexible PVC	2,581*	4,271*
Recovinyl	Flexible PVC applications	18,837	73,048
TEPPFA (incl. Recovinyl)	Pipes & fittings	38,692	40,887
ERPA via Recovinyl (incl. CIFRA and Pack-Upgrade Project)	Rigid PVC films	5,620	19,431
Recovinyl (incl. Vinyloop Ferrara)	Cables	88,477	103,131
TOTAL		362,076	444,468

* Tonnage including Norway and Switzerland

Figure 53 Example of PVC window collection at end-of-life

Photo: Rewindo Fenster-Recycling-Service GmbH

→ **Metal**

Eurowindoor estimates approx. between 15% and 17% of all windows to have metal frames, either steel (5%) or aluminium (95%). While steel frames allow particular slim profiles, aluminium frames are completely weather resistant and there is a greater design variety. Profiles for windows mode of steel are produced by a few European 'System houses' (Schüco, Jansen, Forster etc.).

Aluminium

There is no official statistics assessing the end of life collection rate of aluminium building products. A case study of the TU Delft on the COLLECTION OF ALUMINIUM FROM BUILDINGS IN EUROPE (Delft study, published by the EAA in 2004[39]) showed that more than 96% of the Al is collected from demolition sites.

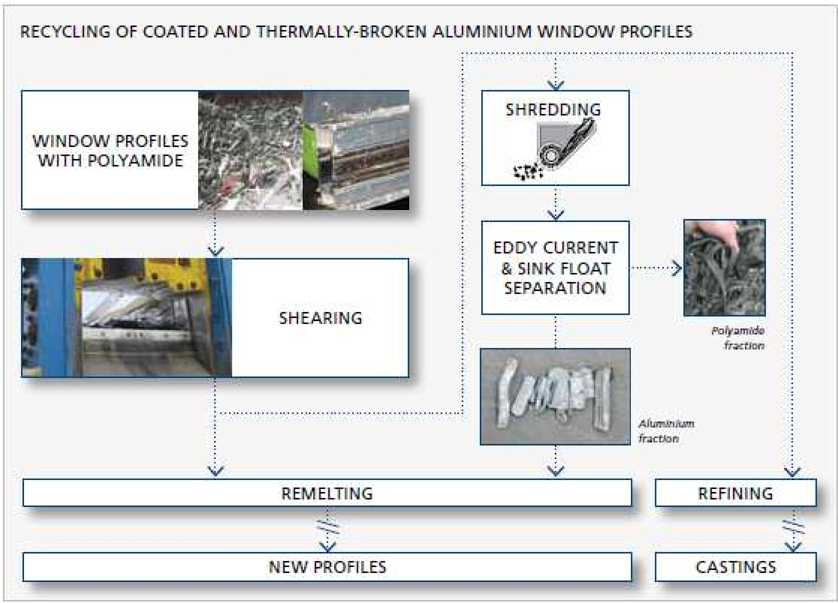
[39] EAA publication of study "COLLECTION OF ALUMINIUM FROM BUILDINGS IN EUROPE" by Delft University of Technology, 2004 (available from http://www.alueurope.eu/building-recycling/). The summary table on page 3 shows collection rates of generally above 92% up to 98% (average 95%). However in some buildings such rates may not be achieved (usually influenced by wide dispersion of aluminium over building waste streams and low weight share of aluminium in overall waste).

The collection rate is even more important for big pieces like aluminium frames which are systematically collected. However, considering the high value of Al scrap (currently about 1€/kg), the economic incentives remain to maintain such a high collection rate. Hence, for Al framing we may assume a collection rate close to 96%.

Recycling

Regarding the recycling itself, there are typically 3 possible recycling routes (see details at http://www.alueurope.eu/wp-content/uploads/2012/01/Sustainability-of-Aluminium-in-Buildings.pdf) illustrated in the below diagram:

Figure 54 Example of end-of-life processes for aluminium windows



Depending on the collection scheme and national/local practices, the Al frame can be mixed with other Al scrap or can be kept separated from other Al scrap, allowing a true close loop recycling. In the latter case, after removal of the thermal break and other contaminants though mechanical treatment (Shearing/shredding) followed usually by Eddy current separation, sink-float separation and more recently sensor based sorting, the clean scrap flow is sent directly to remelting to produce back ingot used for profiles. This is for example the collection system developed in Germany through A/U/F[40].

The refining route is similar but the old framings are mixed with other scrap along the scrap preparation route so that the scrap lot composition is quite mixed and is then used by refiners to produce casting alloys (containing more alloying elements) which are used mainly in foundries to produce for example cast engines.

This refining route is still dominating in Europe but the A/U/F type schemes are under discussion in several MS.

The remelting route is more efficient and metal losses are usually limited to 2 to 4%. The refining route generates metal losses between 4 to 8% losses.

On average, it can be assumed then that the metal losses resulting from the scrap preparation and melting reach about 5%. (More details about metal losses can be derived from the following paper: U.M.J. Boin and M. Bertram “Melting Standardized Aluminium Scrap: A Mass Balance Model for Europe,” JOM 57 (8) (2005), pp. 26–33

Overall recycling rate of Al window frames

Based on above information, EAA considers that today the end of life recycling rate (considering collection, scrap preparation and melting losses) of Al framing for windows is about **93%.** This figure appears as a reasonable estimate considering above metal losses.

Steel

Steel is 100 % recyclable. It can be reused over and over again without any loss of quality. Scrap is therefore a valuable raw material for steel production.

[40] www.a-u-f.com

Because of its value, there is a well-established market for steel scrap. Steel in cars, for example, is recycled at a rate of more than 95 per cent. Steel packaging is recycled by more than 71 per cent in Europe. In 2010 the total amount of scrap used for European steelmaking was 96 million tonnes and total European steel production was 173 million tonnes. At present, about 50 per cent of the total EU steel production is derived from recycled steel scrap[41].

European Ferrous Recovery & Recycling Federation stated 2013, that “at the present time there is more ferrous scrap collected in Europe than is needed”. The steel industry recycling rates[42] are shown below.

Table 37 Steel recycling rates for several scrap sources

Market	2007 (est.)	2050 Target
Construction	85%	90%
Automotive	85%	95%
Machinery	90%	95%
Appliances	50%	75%
Containers	69%	75%
Total	83%	90%

According to www.steel.org 95% of the steel taken from commercial construction demolition sites was recycled in the US in 2002. Therefore we will assume also a 95% recycling rate.

→ **Wood**

Frames of wooden windows can – due to the paints and the preservatives used, or the deterioration in quality of wood - in general only be used energetically or go to landfills. The recycling potential of wood for the re-use in particle board industry, which is quite established for a range of other wooden products, is in general blocked due to the presence of coat(s) of paint and the biocidal preservatives used to obtain the required service life. There are no figures available on the percentage of wood from wooden windows going to landfills. For wood as a renewable material and in consideration of the long use phase, the thermal use is a widely accepted end use.

The Dutch window manufacturers association NVBT has commissioned LCA studies in which a recycling scenario was compared with a incineration scenario. Assuming complete recycling/reuse at a location 50 km away from where the waste originates, the recycling scenario scores a positive effect only for (unsustainably sourced) tropical wood. Windows from other woods are better off being incinerated.

This study assumes that 0% of wood from windows is recycled and most of the wood is recovered (incineration with heat recovery). Assumed is a (heat) recovery percentage of 80%, allowing some 10% for incineration without heat recovery and 10% going to landfill as pro memori inputs.

→ **Conclusion recycling (and recovery) of window materials**

For the Ecoreport the information presented above has led us to make the following assumptions regarding end-of-life of average windows.

[41] www.eurofer.org

[42] Source: www.worldsteel.org, Fact sheet: The three Rs

Table 38 End-of-life scenarios for windows, presented by material type[43]

MEERP #	Description	Bulk Plastics	TecPlastics	Ferro	Non-ferro	Coating	Electronics	"Misc.	Refrigerant	Mercury	Extra	Auxiliaries	TOTAL
	main material flow	PV		St	Al			Gl			Wo		
263	EoL mass fraction to re-use, in %	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0.0%
264	EoL mass fraction to (materials) recycling, in %	7%	7%	95%	95%	0%	0%	10%	0%	0%	0%	0%	30.2%
265	EoL mass fraction to (heat) recovery, in %	83%	83%	0%	0%	0%	0%	25%	0%	0%	80%	0%	34.2%
266	EoL mass fraction to non-recov. incineration, in %	10%	10%	5%	5%	100%	100%	0%	100%	100%	10%	100%	4.0%
267	EoL mass fraction to landfill/missing/fugitive, in %	0%	0%	0%	0%	0%	0%	65%	0%	0%	10%	0%	31.6%
268	TOTAL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100.0%
269	EoL recyclability	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg	avg

4.6. Technical Product Life

It can be expected, that the average lifetime of a window is approx. 40-50 years if the product is used according the intended use and maintained / serviced properly. The analysis of the market data (TASK 2) results in a lifetime of a window in that range.

If used according to the intended use, insulating glass units (IGUs) can be expected to have a service life of 25 to 30 years. Therefore it has to be assumed that the IGU and also the gaskets has to be replaced once during the use phase (of more than 30 years) of a window. If the window itself lasts only maximum 30 years, then no IGU replaced is assumed.

In many cases however, windows may be replaced before reaching the end of their technical life. This may be more typical for commercial buildings where retrofitting and renovation is more frequent.

[43] Source: Own estimates based on data presented in TASK 3 and 4

CHAPTER 5 RECOMMENDATIONS

According the MEErP methodology this Chapter is to make recommendations on:

- Refined product scope from the technical perspective
- Barriers and opportunities for Ecodesign from a technical perspective
- The typical design cycle for this product and thus appropriate timing of measures.

5.1. REFINED SCOPE

The TASK 4 Technical analysis did not result in further information that requires a revision or fine-tuning of the study scope from the technical perspective.

The product scope shall remain on windows. Additional solar shading devices and shutters should be considered at least for the evaluation of the energy demand of buildings.

The exclusion of certain types of windows from scope as defined in TASK 1 continue to apply.

5.2. BARRIERS AND OPPORTUNITIES

Barriers and opportunities for Ecodesign from a technical perspective have been dealt with in TASK 1. It must be kept in mind, that production equipment especially of SMEs producing wooden windows may have performance limits. For example the manufacturing of bigger wooden profiles able to hold IGU-Units with three panes could require new and bigger tools, that also require more powerful machinery which could result in a heavy financing burden.

Newly developed building products which may contain risks for health and safety are often heavily regulated by the building codes of the member states. Even though they might be put on the market under the CPR, their usability and thus the market size may be limited. For new products the authorities in the member states often require additional approvals for which additional test evidence is needed.

Windows in regard to their product life cycle may be considered as comparatively mature products. As the U_w-value, which may be considered as one of the main criteria in regard to energy consumption in the use phase, for current state of the art products is as low as 0.7 to 0.9 W/m^2K compared to 5.8 some 40 years ago. It is estimated, that further improvements may result in Uw-values lower than 0.7 W/m^2K, but the necessary design changes are estimated to result in un-proportional additional costs – compared to the cost of other measures to improve the total energy consumption of buildings.

5.3. TYPICAL DESIGN CYCLE

The typical design cycle determines the absolute minimum time period that manufacturers need in order to be able to adapt to changing legislation, provided that other criteria for requirements, such as other impacts on consumers and business are met.

The typical design cycle is closely related to the required improvement.

As the new design options are already existing products, the time period to prepare for legislation is dominated by the time required to adapt existing production facilities to the required window properties (buy and install new machinery). Design changes using available, yet improved technology, like different Isolating Glass Units may be put to market within months.

The typical design cycle for an updated windows profile may be estimated with 24 to 36 month, depending - among other - on the necessary involvement (and capacity) of testing by Notified Bodies for CPR required for the type testing of essential characteristics.

ANNEX A
CALCULATION OF THE ENERGY PERFORMANCE OF WINDOWS USING THE SINGLE ROOM

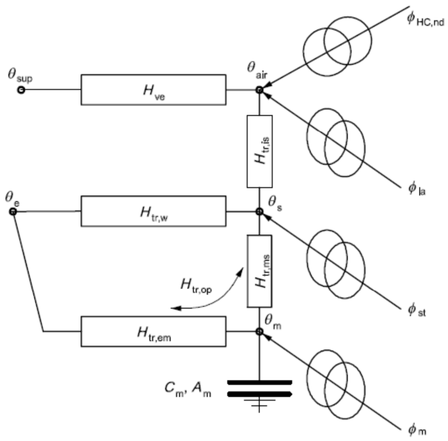
A.1 Methodology

The calculation procedure is based on:

- EN ISO 13790 and
- ISO 18292.

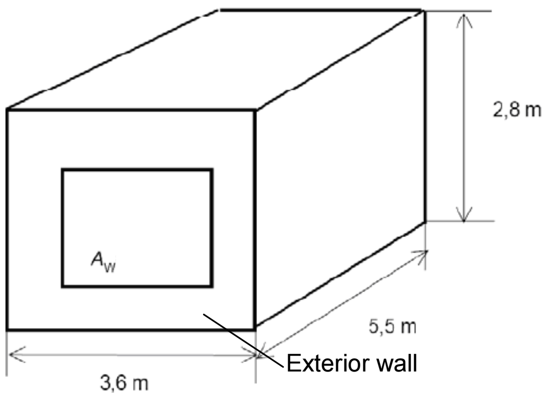
The simple hourly dynamic calculation method according to EN ISO 13790 used for the study is able to model thermal transmission, heat flow by ventilation, thermal storage and internal and solar heat gains in the room. The model is based on an equivalent resistance-capacitance (R-C) model. It uses an hourly time step. Figure 1 shows the relevant RC network model.

Figure A-55: RC network for the simple hourly method according to EN ISO 13790



To investigate the impact of different window systems on the energy demand for heating and cooling, the windows are “integrated” in the exterior wall of a single room/zone (see figure 2). The exterior wall with the window is oriented to North, East, South and West to consider the effect of different window orientations.

Figure A-56: Single room model according to EN 13791; V = 55,4 m³; A_{floor} = 19,8 m²



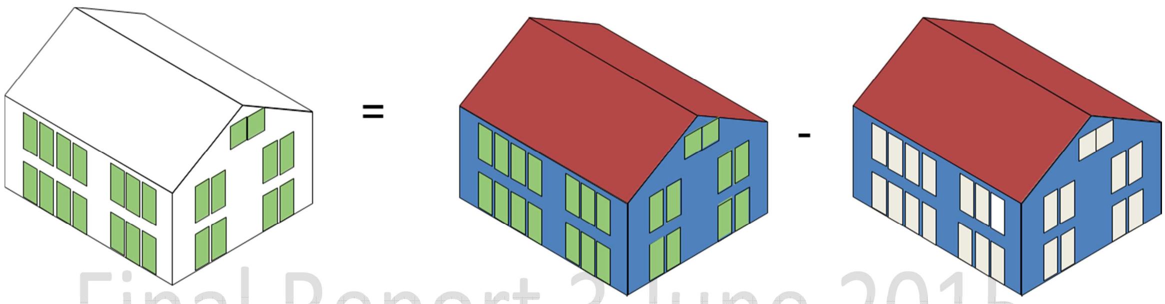
The heating and/or cooling need for the simulated room is found by calculating for each hour the need for heating or cooling power, that needs to be supplied to, or extracted from, the room, to maintain a certain minimum or maximum set-point temperature.

Using the hourly calculation method, ISO 18292 does not give an explicit equation for the determination of the energy performance value of the window system but states that the annual heating and cooling energy associated with the fenestration system has to be calculated. The calculated energy demand for heating and cooling is equivalent with the energy performance value.

To separate the energy demand associated to the window from the total energy demand of the room two calculations are performed

1. Calculation of the energy demand of the room with the "real window" installed
2. Calculation of the energy demand of the room with an "adiabatic window" ($U_W = 0$, g_W=0, no air leakage) installed

Figure A 57 Visualisation of calculation procedure for window energy performance



The difference of these two calculations is the energy demand that can be associated to the window.

$$Q_{heat,window} = Q_{heat,room\ \ with\ \ real\ \ window} - Q_{heat,room\ \ with\ \ adibatic\ \ window}$$

$$Q_{cool,window} = Q_{cool,room\ \ with\ \ real\ \ window} - Q_{cool,room\ \ with\ \ adibatic\ \ window}$$

This approach was also recommended in a position paper ("Window Energy rating: a plea from the fenestration industry") published in June 2010 by the following stakeholders:

- European Aluminium Association
- European Solar Shading Organization
- Eurowindoor
- Glass for Europe

Furthermore the approach was used already in the past by several scientific institutions to calculate the energy performance of windows.

Of course several building properties or boundary conditions need to be defined (or assumed) in order to complete the calculations. The following boundary conditions must be defined for the calculation:

External Climate

- External Temperature Te
- Solar Irradiance (N;W;E;S)

- pressure difference Δp to calculate the volume flow caused by infiltration of the window

Internal Climate

- Temperature Limit for Heating
- Temperature Limit for Cooling

Building

- Dimensions
- Heat Capacity (thermal mass)
- U-value of the envelope (exterior wall, roof, floor)
- Orientation of the windows
- Area of the windows
- slope of the roof windows

Other parameters

- ventilation rate n
- increased ventilation rate (ventilative cooling)
- internal loads
- set points of activation for increased ventilation rate
- set points of activation of the sun shading
- usage of the building (e.g. 24h/7 days a week

The calculations will have to rely on the use of 'reference buildings' to allow such calculations. The calculations will be performed on a simplified hourly basis.

A.2 Data for the external climate

To perform the calculation, hourly data of the relevant parameters for the external climate are needed:

- External Temperature T_e in °C
- Solar Irradiance I_s in W/m^2 for north oriented windows
- Solar Irradiance I_s in W/m^2 for east oriented windows
- Solar Irradiance I_s in W/m^2 for south oriented windows
- Solar Irradiance I_s in W/m^2 for west oriented windows

For three different “climatic conditions”, the hourly data were calculated with the Meteonorm Database choosing one “representative” city for each case.

Table 39 Summary of the three investigated climates

	C1 North	C2 Central	C3 South
Location	Helsinki	Strasbourg	Athens
HDD 18°C	3537 K d	2813 K d	1010 K d
CDD 18°C	119 K d	343 K d	1226 K d
Total solar Irradiation	1054 kWh/(m^{2}a)	1143 kWh/(m^{2}a)	1795kWh/(m^{2}a)

Figure A-58: Mean external temperature T_e and global solar irradiance per month for northern climate

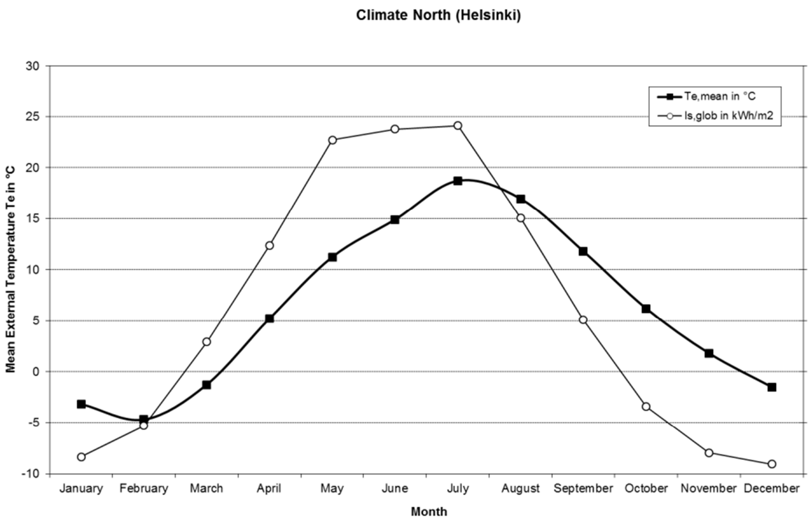


Figure A-59: Mean external temperature T_e and global solar irradiance per month for central climate

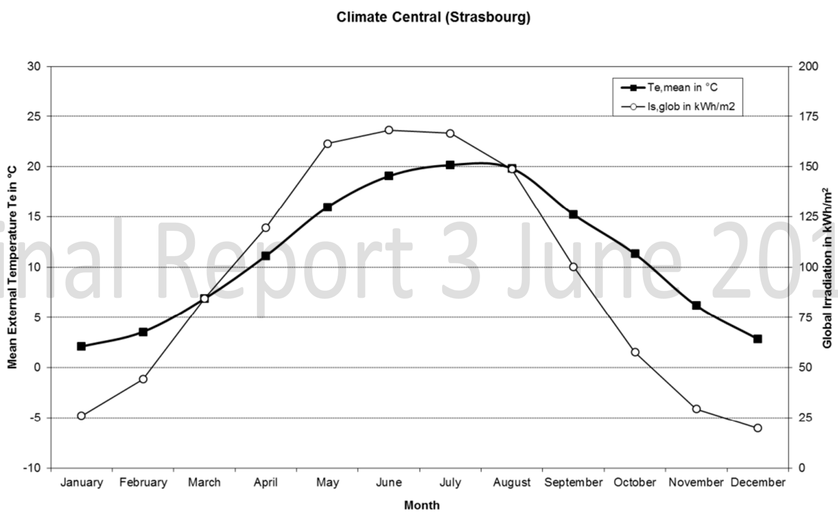
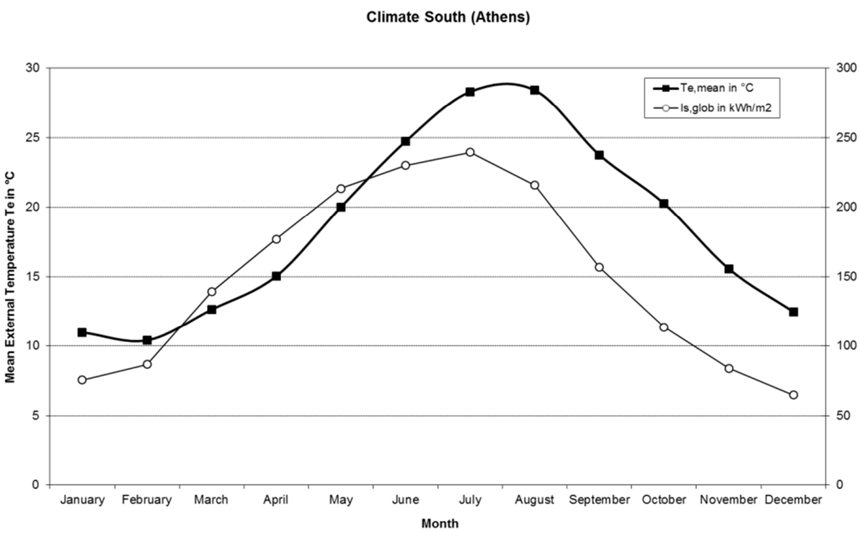


Figure A-60: Mean external temperature T_e and global solar irradiance per month for southern climate



A.3 Boundary conditions

For the calculation of the "base case" a set of boundary conditions were defined.

Table A-40 Boundary conditions and other parameters used for the calculation of the base case

Parameter		Source
External Climate		
External Temperature T_e	Complete year, hourly data of T_e (Three different climates)	Meteo Norm Database
Solar Irradiance I_s	Complete year, hourly data of I_s for N;E;S;W (Three different climates)	Meteo Norm Database
Pressure Difference Δp	Δp=6 Pa	ISO 18292
Internal Climate		
Temperature set point for heating	T_i = 20°C	Table G.12 EN 13760
Temperature set point for cooling	T_i = 26°C	Table G.12 EN 13760
Room		
Dimensions	3,6 x 2,8 x 5,5 m^3	EN ISO 13791
Heat Capacity	heavy C^*_m = 260 000 J/m^2K (A_{floor})	EN ISO 13790
U-value exterior wall	U_{wall}=0.8 W/m^2K	a.o. based on Ecofys for Eurima
Ventilation (General)	n=0.5 h^{-1}	
Increased Ventilation to allow ventilative cooling	n=2.0 h^{-1} for Ti>23°C and Ti>Te	
Internal heat sources (related to floor area)	Q_i =5 W/m^2	DIN 4108-2 , see also Table G.8 EN 13790
Usage	24 h/7 days a week	
Window		
U_w value	Different values (see table)	
g-value	Different values (see table)	
Size	2,18 m x 1,48 m + 1,48 x 1,23 A_W = 5.05 m^2 (=>Aw/Afloor = 0,26)	
Frame fraction	F_F=30%	
Infiltration	Different values (see table)	EN 12207
Sun shading		
Fc-value	Fc = 1 and 0.1	

Set point for activation of the sun shading	I_s > 300 W/m² and T_e > 15°C	EN ISO 13790, Annex G: *Unless otherwise specified at national level, the solar shading shall be taken as being switched on if the intensity of the solar radiation on the surface at the given hour exceeds 300 W/m2 and switched off if the hourly value is below this value.*
Additional ΔR **Note: Also applied when the sun shading is in active position during the day**	ΔR=0.17 m²K/W Sunset to sunrise complete year	EN 10077-1 Table G.1. Average air permeability Roller Shutter made out of wood or plastic

To analyse the impact of specific boundary conditions/parameters the calculations were also performed with changed parameters.

Table A-41 Variations

No.		Description
1	Base Case	Boundary conditions according to Table xxx
2	Heat Capacity	As Base Case but with reduced heat capacity C^*_m = 165 000 J/m²K (A_{floor}) (medium according to EN 13790)
3	Window area	As Base Case but with reduced window area 2,18 m x 1,48 m A_W = 3.23 m² (=>Aw/A_{floor} = 0,16)
4	Natural ventilation	As Base Case but no increased ventilation for ventilative cooling
5	"Office building"	Reduced heat capacity C^*_m = 165 000 J /m²K (A_{floor}) Increased Window area: 10 m² (fully transparent façade) (=>Aw/A_{floor} = 0,65) Increased internal load by 50% (Q_i = 7,5W/m²) No openable elements => no ventilative cooling

A.4 Results

The results given are calculated for an average orientation assuming 25% in each direction (North, East, West and South).

Absolute values are stated in kWh/m² related to one m² of the window.

A.4.1 Base Case

A.4.1.1. Calculated energy demand

Table A-42 Calculated energy demand – base case

No.	U_w in $W/(m^2$	g	Airtightness class	Energy use in kWh/(m^2 a)related to m^2 window area								
				Zone North			Zone Central			Zone South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5,8	0,85	2	600,8	18,7	619,5	365,0	36,6	401,6	75,9	211,1	287,0
2a	2,8	0,78	3	222,3	28,5	250,8	122,4	48,4	170,9	9,2	212,1	221,3
3a	1,7	0,65	4	99,8	23,6	123,4	49,2	41,3	90,4	-3,0	178,7	175,6
4a	1,3	0,60	4	67,2	21,1	88,2	30,1	37,6	67,7	-5,5	164,9	159,3
5a	1,0	0,55	4	43,8	18,1	61,8	16,7	33,3	50,0	-7,1	150,2	143,1
6a	0,8	0,60	4	21,1	24,0	45,0	2,3	41,4	43,6	-9,2	169,2	160,1
7a	1,0	0,58	4	41,0	20,8	61,8	14,6	37,1	51,8	-7,5	160,5	152,9
8a	0,6	0,47	4	13,7	13,2	26,9	0,0	26,3	26,3	-8,8	126,3	117,5
9a	2,8	0,35	3	282,5	3,1	285,6	170,8	9,4	180,2	33,8	85,8	119,6
10a	1,3	0,35	4	95,7	4,8	100,4	51,7	12,7	64,4	1,2	87,5	88,6
11a	0,8	0,35	4	45,8	5,5	51,2	21,1	14,0	35,1	-4,7	88,7	84,0
with shutter												
1b	5,8	0,85	2	434,8	1,0	435,8	266,7	10,7	277,4	45,8	88,1	134,0
2b	2,8	0,78	3	165,9	1,7	167,6	90,0	14,6	104,6	3,3	77,7	81,0
3b	1,7	0,65	4	76,0	1,3	77,4	35,7	12,2	47,9	-4,9	63,8	58,8
4b	1,3	0,60	4	52,5	1,2	53,7	21,8	11,1	33,0	-6,6	58,6	52,0
5b	1,0	0,55	4	34,8	1,0	35,8	11,8	9,9	21,7	-7,7	53,4	45,7
6b	0,8	0,60	4	15,2	1,4	16,6	-0,9	12,2	11,3	-9,5	58,7	49,2
7b	1,0	0,58	4	32,1	1,2	33,3	9,6	11,0	20,6	-8,1	56,5	48,4
8b	0,6	0,47	4	10,3	0,7	11,0	-1,8	8,0	6,1	-9,0	45,0	36,1
9b	2,8	0,35	3	224,6	0,2	224,8	137,8	3,7	141,5	25,7	37,3	63,0
10b	1,3	0,35	4	80,7	0,3	81,0	43,9	4,4	48,3	0,0	33,8	33,9
11b	0,8	0,35	4	39,8	0,4	40,1	18,1	4,7	22,9	-5,0	33,2	28,2

Figure A-61: Absolute energy demand for heating and cooling for the Climate North, Base Case

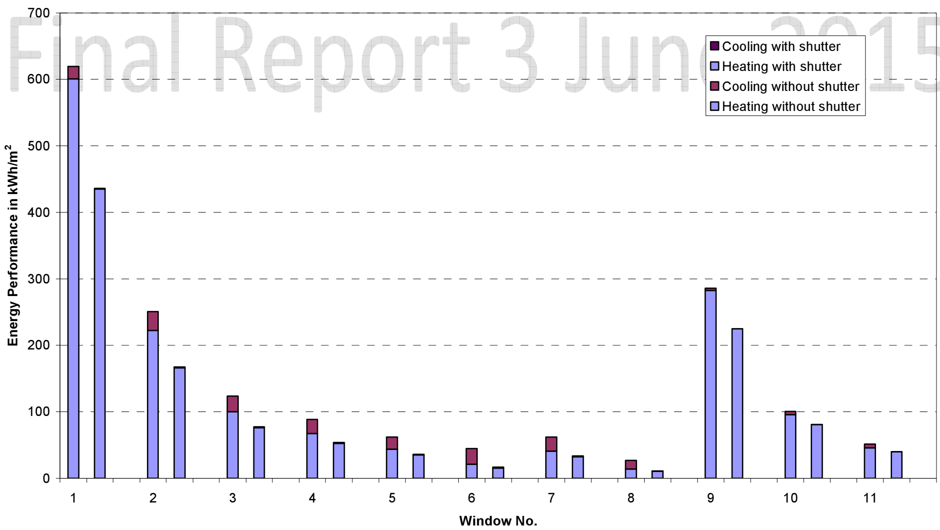


Figure A-62: Absolute energy demand for heating and cooling for the Climate Central, Base Case

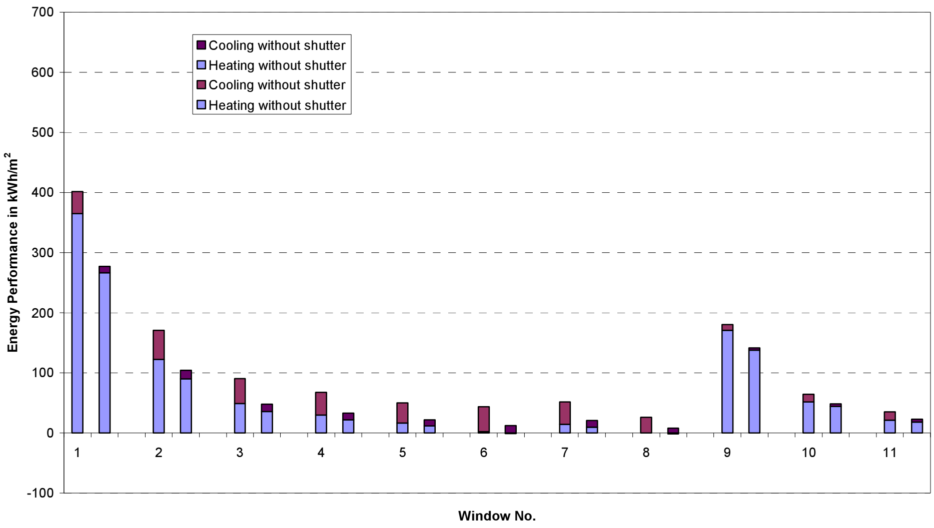
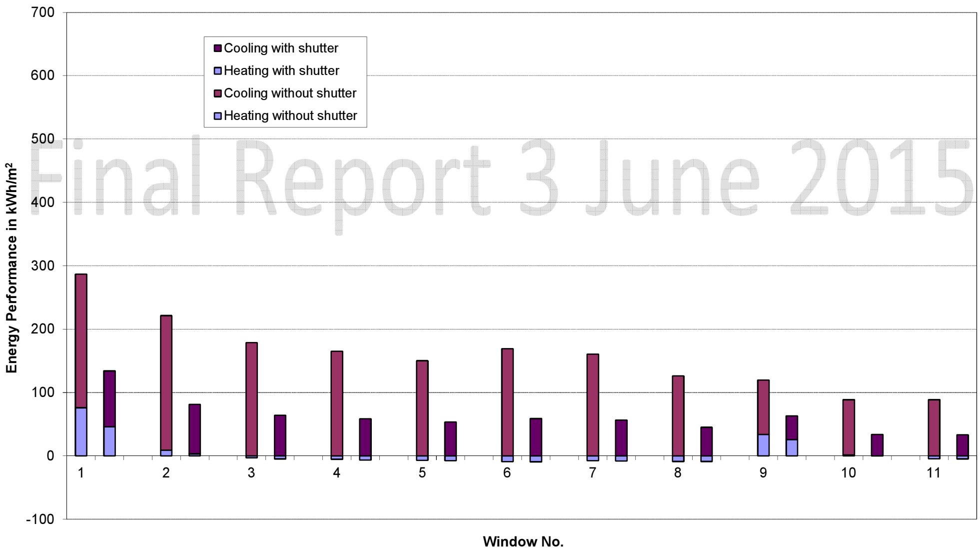


Figure A-63: Absolute energy demand for heating and cooling for the Climate South, Base Case



A.4.1.2. Relative total energy demand

Figure A-64: Relative total energy demand for the Climate North; Base Case

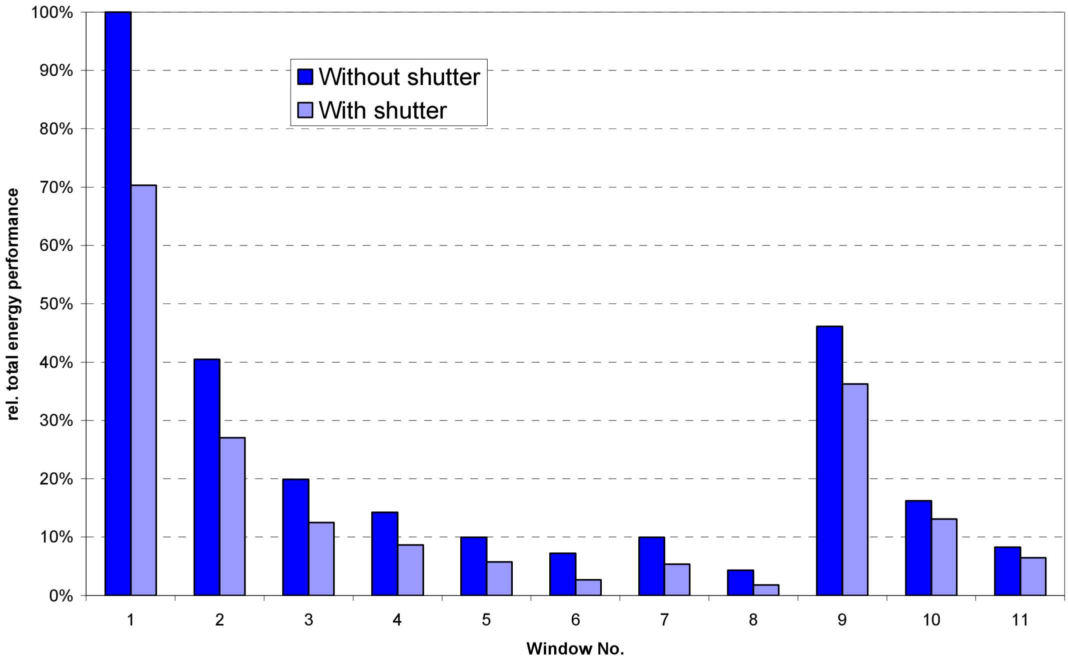


Figure A-65: Relative total energy demand for the Climate Central, Base Case

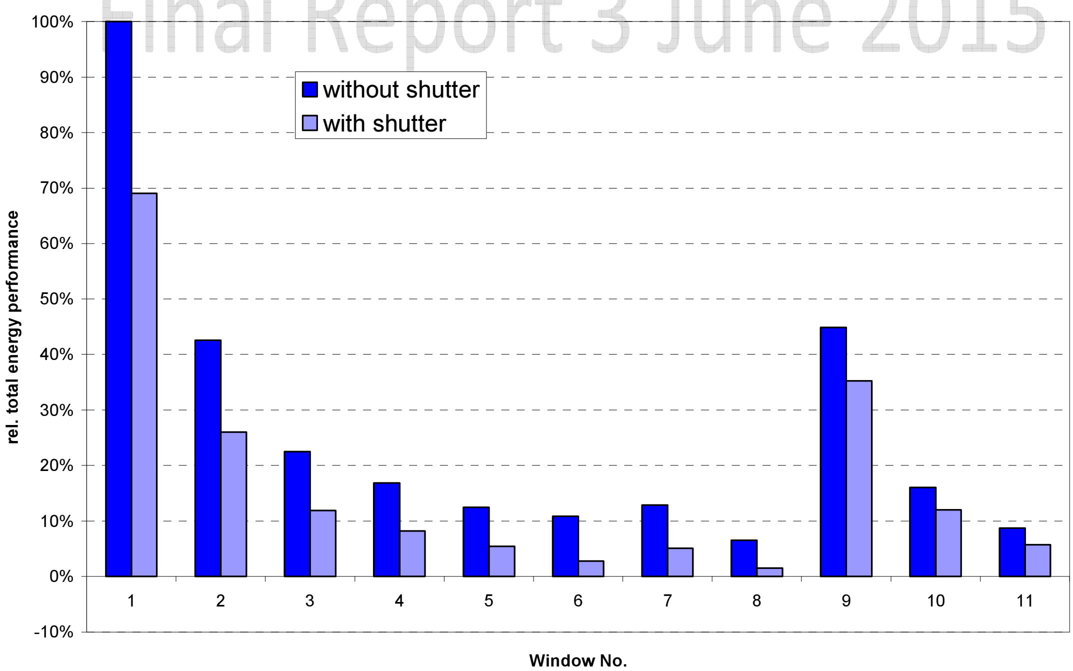
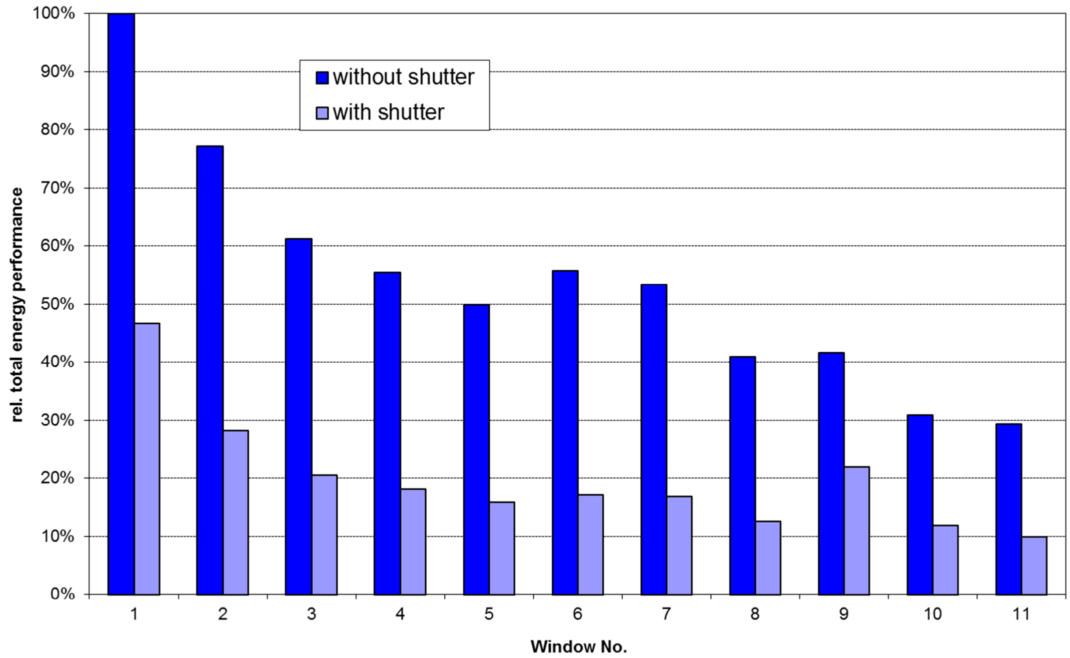


Figure A-66: Relative total energy demand for the Climate South, Base Case



A.4.2 Reduced Heat Capacity

A.4.2.1. Calculated energy demand

Table A-43 Calculated energy demand – reduced heat capacity

No.	U_w in W/(m²)	g	Airtightness class	Energy use in kWh/(m² a) related to m² window area								
				Zone North			Zone Central			Zone South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5,8	0,85	2	610,4	27,5	637,9	376,4	49,8	426,2	86,6	225,9	312,6
2a	2,8	0,78	3	228,8	38,7	267,5	129,1	62,4	191,5	12,8	226,5	239,4
3a	1,7	0,65	4	104,5	32,1	136,7	52,9	52,5	105,5	-1,7	189,8	188,1
4a	1,3	0,60	4	71,1	28,8	99,9	33,3	47,8	81,1	-4,7	174,8	170,1
5a	1,0	0,55	4	47,2	24,9	72,1	19,4	42,4	61,8	-6,6	158,8	152,2
6a	0,8	0,60	4	24,6	31,9	56,5	4,9	51,9	56,7	-8,9	179,4	170,6
7a	1,0	0,58	4	44,7	28,3	73,0	17,3	47,1	64,4	-7,1	170,0	162,9
8a	0,6	0,47	4	16,2	18,6	34,8	1,7	33,5	35,3	-8,6	132,8	124,2
9a	2,8	0,35	3	285,0	5,0	290,0	173,8	13,3	187,1	36,6	89,9	126,4
10a	1,3	0,35	4	97,6	7,3	104,9	53,5	16,8	70,3	2,2	91,0	93,2
11a	0,8	0,35	4	47,6	8,3	56,0	22,5	18,3	40,9	-4,2	92,2	88,0
with shutter												
1b	5,8	0,85	2	431,8	2,1	433,9	265,3	16,6	281,8	52,4	92,0	144,4
2b	2,8	0,78	3	171,8	3,4	175,2	95,5	19,1	114,6	5,6	81,3	86,9
3b	1,7	0,65	4	80,4	2,6	83,0	39,3	15,7	55,0	-4,0	66,3	62,3
4b	1,3	0,60	4	56,2	2,2	58,4	24,8	14,2	39,0	-6,0	60,8	54,8
5b	1,0	0,55	4	38,0	1,8	39,8	14,2	12,7	26,9	-7,3	55,2	47,9
6b	0,8	0,60	4	18,6	2,7	21,3	1,5	15,4	16,9	-9,3	61,0	51,7
7b	1,0	0,58	4	35,6	2,2	37,7	12,3	14,0	26,3	-7,8	58,6	50,8
8b	0,6	0,47	4	12,7	1,4	14,1	-0,1	10,2	10,1	-8,8	46,5	37,6
9b	2,8	0,35	3	226,6	0,5	227,1	139,6	4,9	144,5	27,7	38,9	66,5
10b	1,3	0,35	4	82,4	0,6	83,0	45,4	5,7	51,1	0,8	35,1	36,0
11b	0,8	0,35	4	41,5	0,7	42,2	19,5	6,0	25,6	-4,5	34,3	29,8

Figure A-67: Absolute energy demand for heating and cooling for the Climate North, reduced heat capacity

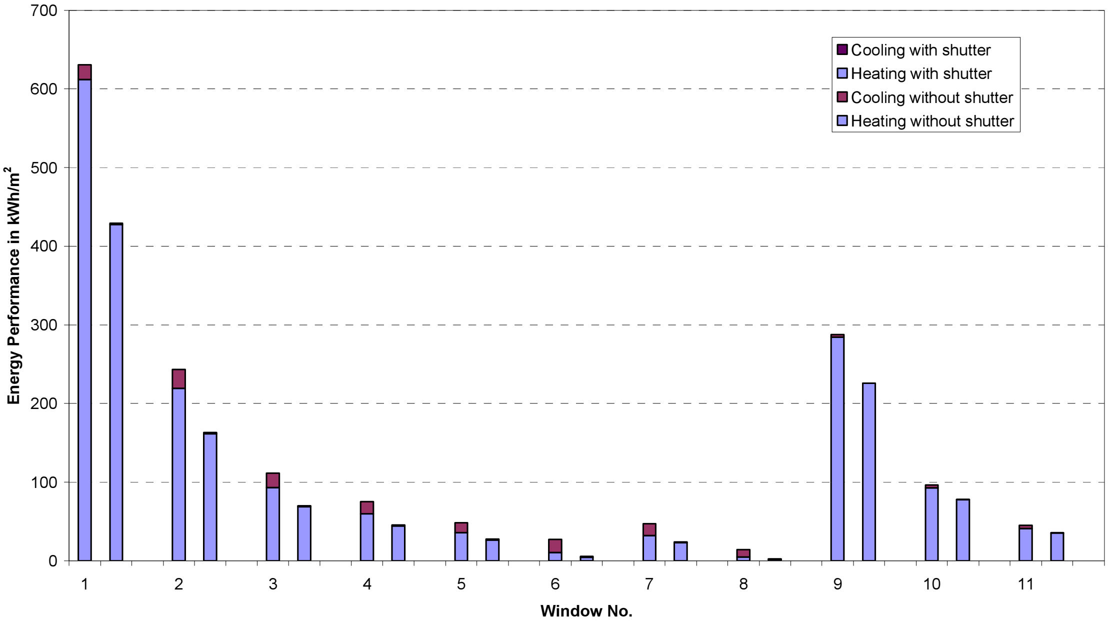


Figure A-68: Absolute energy demand for heating and cooling for the Climate Central, reduced heat capacity

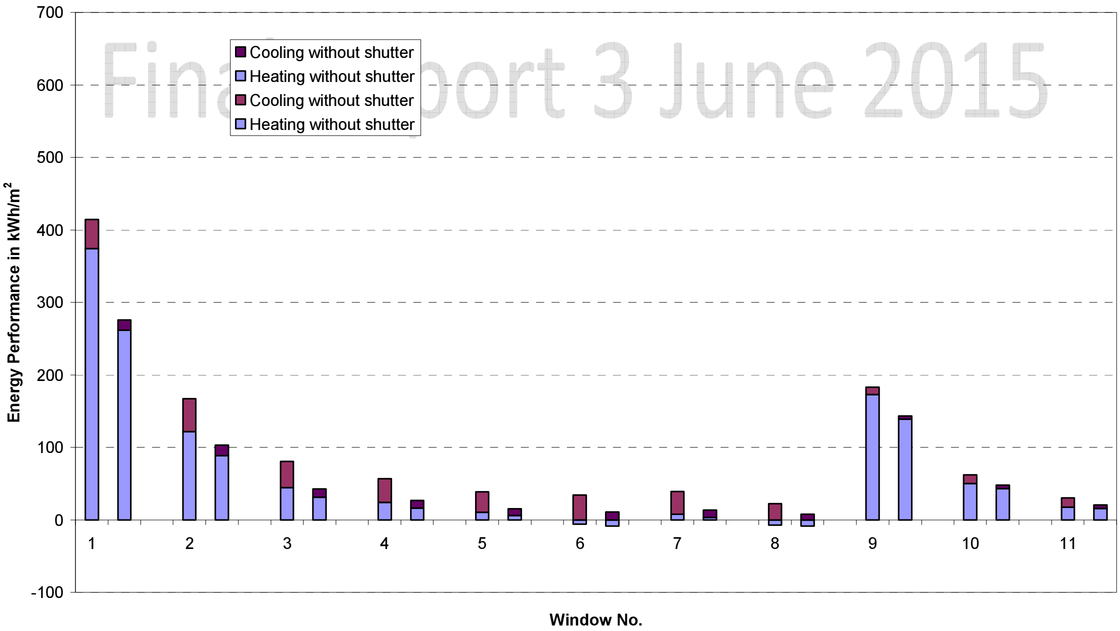
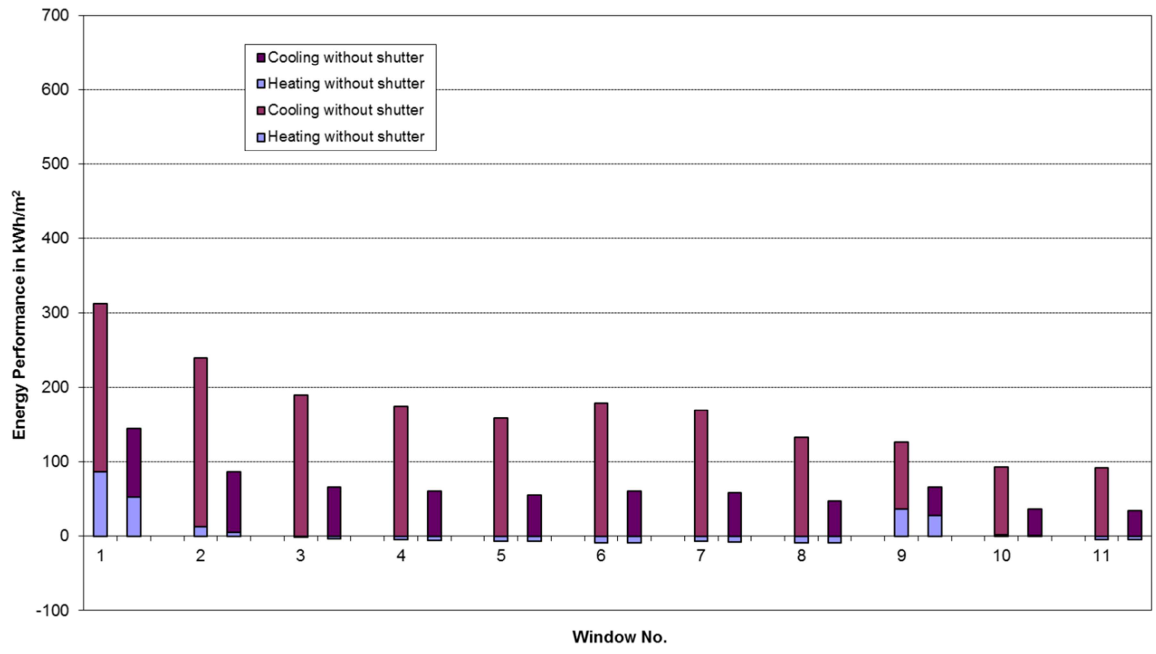


Figure A-69: Absolute energy demand for heating and cooling for the Climate South, reduced heat capacity



A.4.2.2. Relative total energy demand

Figure A-70: Relative total energy demand for the Climate North; reduced heat capacity

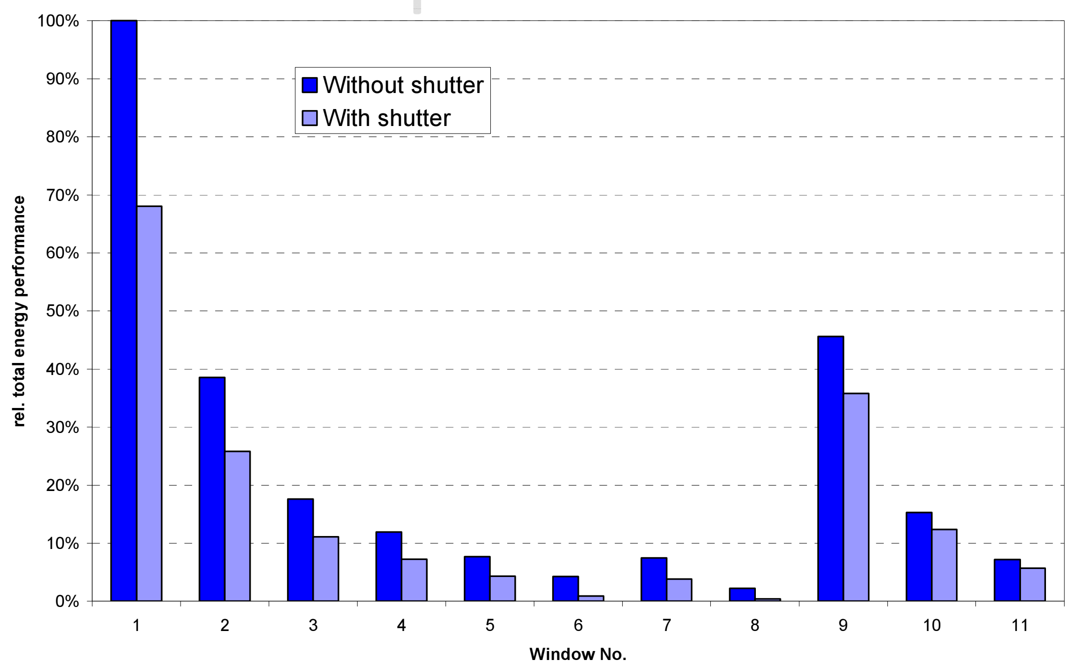


Figure A-71: Relative total energy demand for the Climate Central; reduced heat capacity

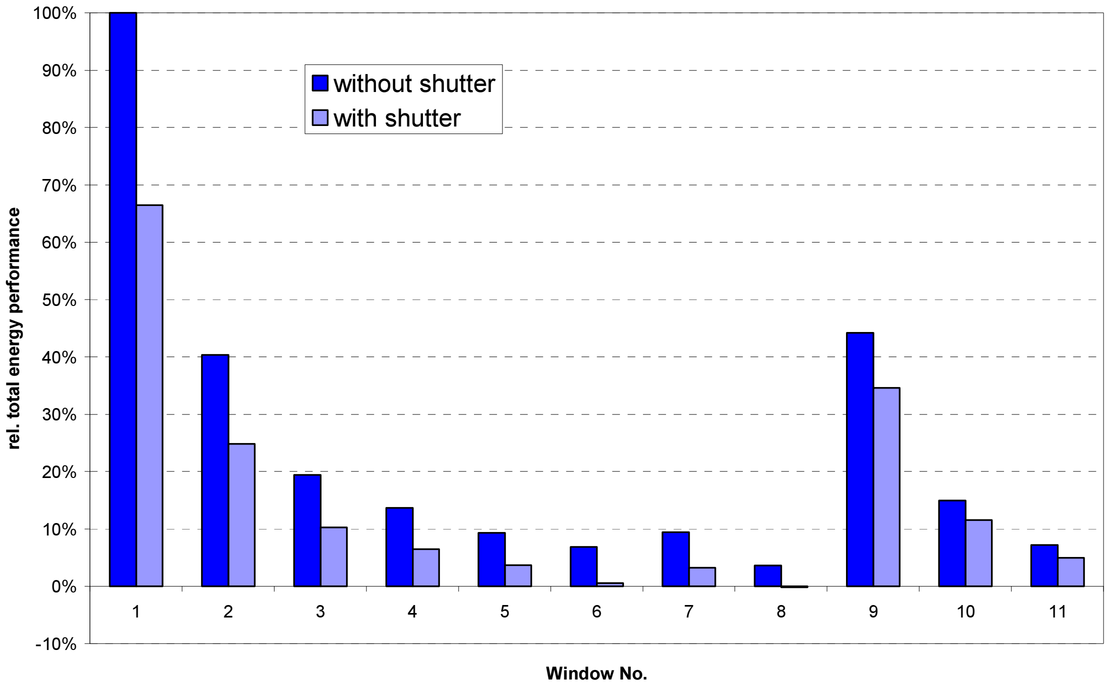
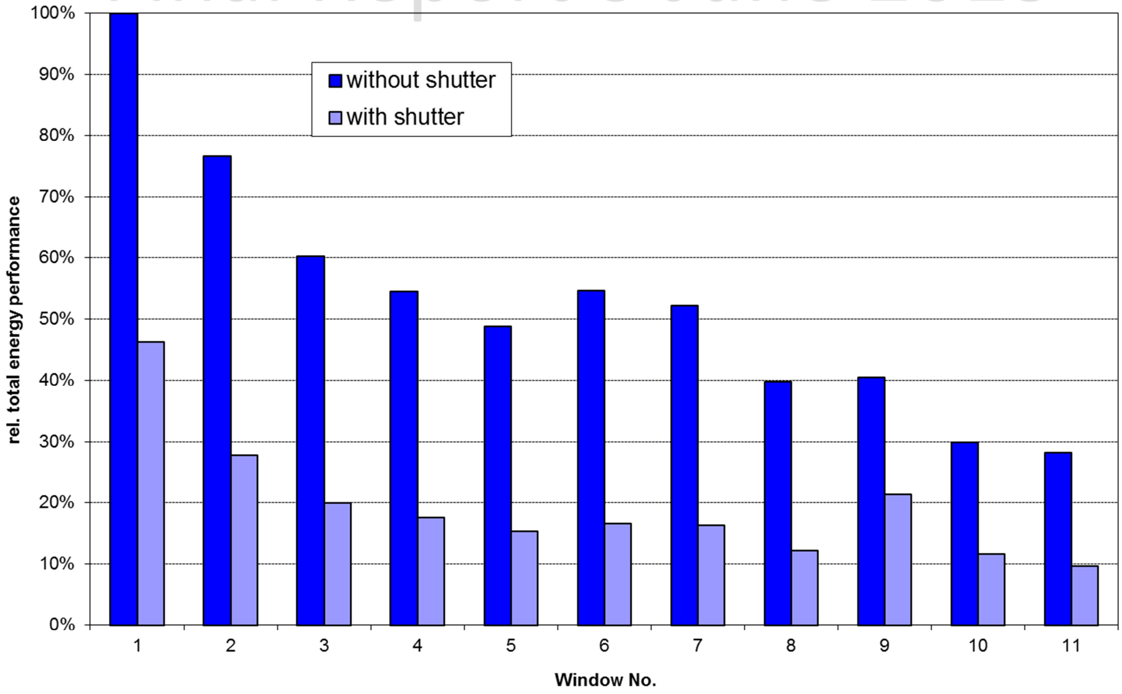


Figure A-72: Relative total energy demand for the Climate South; reduced heat capacity



A.4.3 Reduced ratio window area to floor area

A.4.3.1. Calculated energy demand

Table A-44 Calculated energy demand – reduced window area to floor area

No.	U_w in $W/(m^2$	g	Airtightness class	Energy use in $kWh/(m^2$ a)related to m^2 window area								
				Zone North			Zone Central			Zone South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5,8	0,85	2	604,1	11,9	616,0	365,0	29,2	394,2	71,3	209,0	280,3
2a	2,8	0,78	3	214,1	15,8	230,0	115,9	34,4	150,3	2,5	198,4	201,0
3a	1,7	0,65	4	89,2	11,8	101,0	40,8	27,7	68,5	-11,1	164,3	153,2
4a	1,3	0,60	4	56,0	10,1	66,1	21,3	24,8	46,2	-14,0	151,0	137,0
5a	1,0	0,55	4	32,4	8,4	40,9	7,9	21,7	29,6	-15,8	137,3	121,5
6a	0,8	0,60	4	6,9	11,1	18,0	-8,3	26,5	18,2	-19,0	152,6	133,6
7a	1,0	0,58	4	28,8	9,7	38,5	5,2	24,1	29,3	-16,6	146,1	129,4
8a	0,6	0,47	4	2,7	5,9	8,6	-8,8	16,8	8,1	-17,8	115,5	97,6
9a	2,8	0,35	3	282,4	1,7	284,1	170,5	7,0	177,4	32,2	83,5	115,8
10a	1,3	0,35	4	91,1	2,3	93,4	48,4	8,5	56,9	-3,1	82,4	79,3
11a	0,8	0,35	4	39,6	2,5	42,1	16,2	9,2	25,4	-10,9	82,6	71,7
with shutter												
1b	5,8	0,85	2	421,3	0,8	422,1	256,0	10,5	266,5	41,3	88,4	129,8
2b	2,8	0,78	3	156,5	1,0	157,5	83,6	11,0	94,6	-3,4	75,4	72,0
3b	1,7	0,65	4	65,0	0,7	65,8	27,8	9,0	36,8	-12,9	61,0	48,1
4b	1,3	0,60	4	41,2	0,6	41,8	13,7	8,1	21,9	-14,9	55,7	40,8
5b	1,0	0,55	4	23,4	0,5	23,9	3,6	7,3	10,9	-16,1	50,6	34,4
6b	0,8	0,60	4	1,1	0,7	1,7	-11,1	8,5	-2,6	-19,2	55,2	36,0
7b	1,0	0,58	4	19,8	0,6	20,4	0,8	7,9	8,7	-17,0	53,4	36,4
8b	0,6	0,47	4	-0,5	0,4	-0,1	-9,8	6,0	-3,8	-17,6	42,4	24,8
9b	2,8	0,35	3	223,8	0,1	223,9	137,6	3,3	140,9	24,9	37,0	61,8
10b	1,3	0,35	4	76,4	0,2	76,6	41,9	3,7	45,6	-3,8	32,6	28,8
11b	0,8	0,35	4	34,1	0,2	34,3	14,6	3,9	18,5	-10,6	31,6	21,0

Figure A-73: Absolute energy demand for heating and cooling for the Climate North, reduced ratio window area/floor area

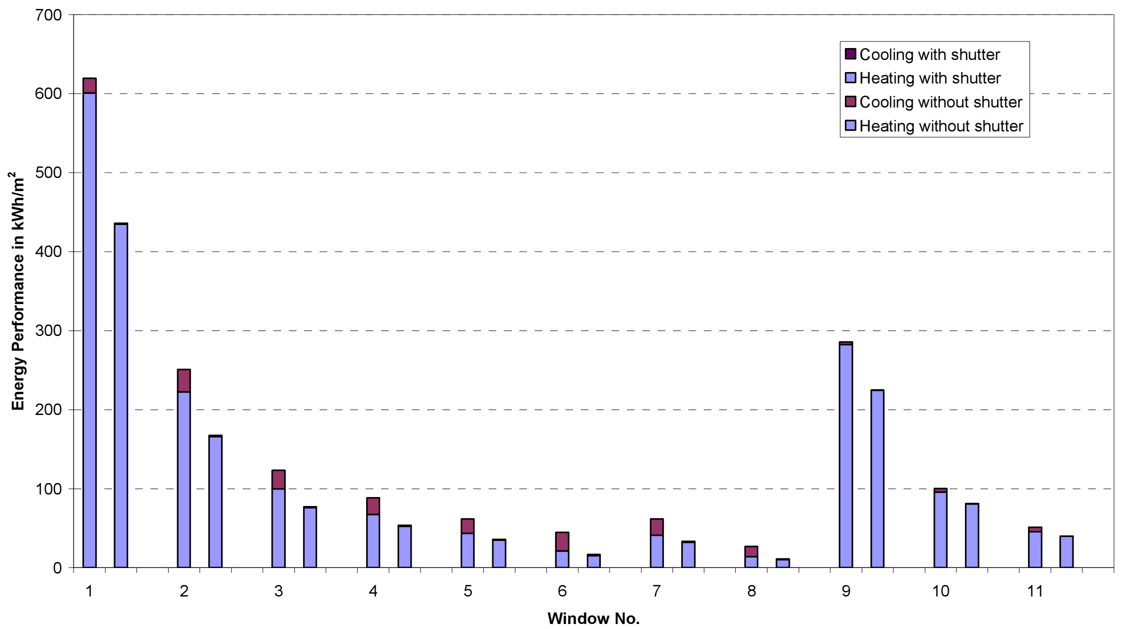


Figure A-74: Absolute energy demand for heating and cooling for the Climate Central, reduced ratio window area/floor area

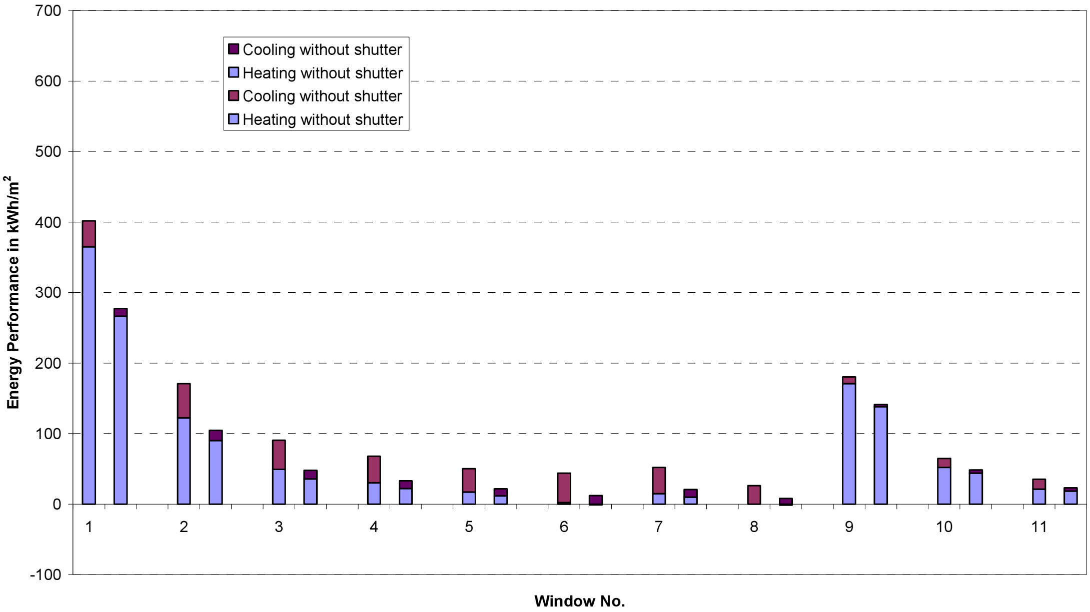
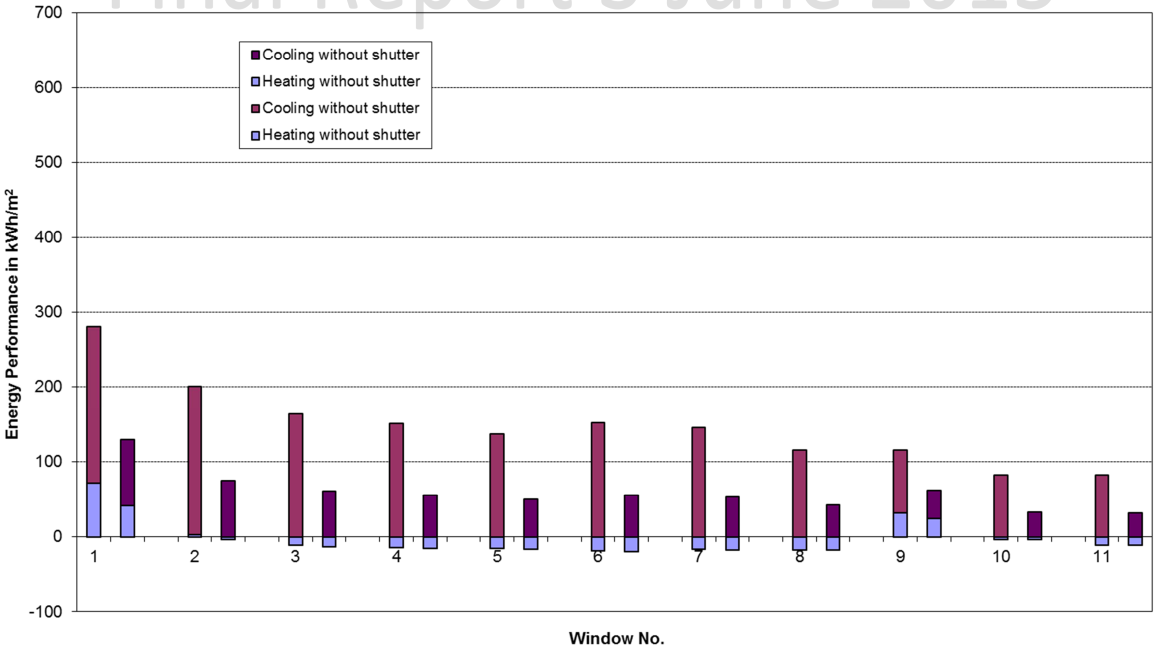


Figure A-75: Absolute energy demand for heating and cooling for the Climate South reduced ratio window area/floor area



A.4.3.2. Relative total energy demand

Figure A-76: Relative total energy demand for the Climate North; reduced ratio window area/floor area

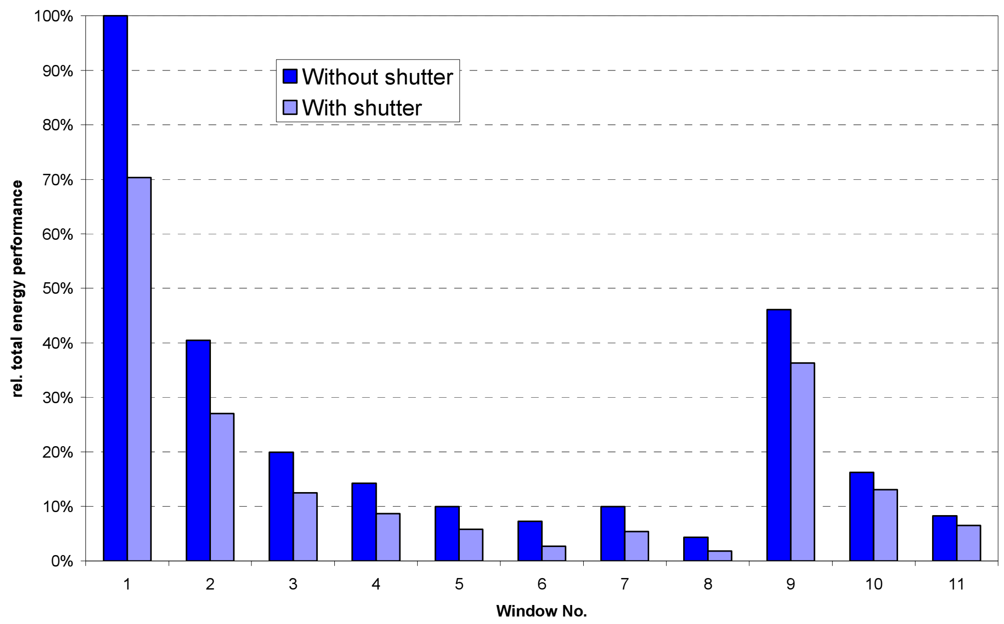


Figure A-77: Relative total energy demand for the Climate Central; reduced ratio window area/floor area

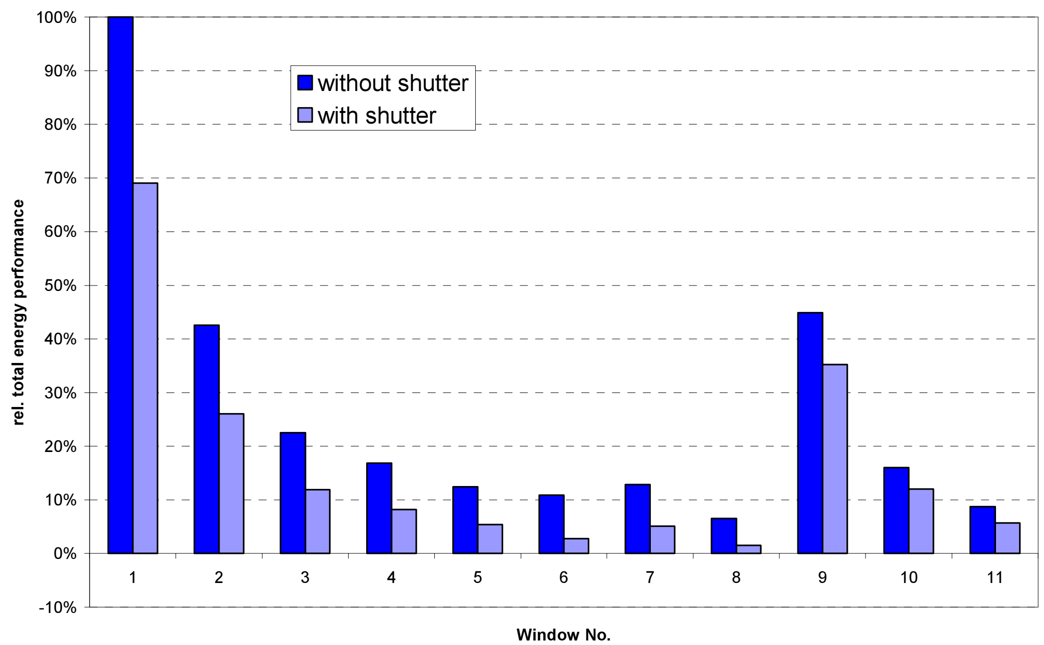
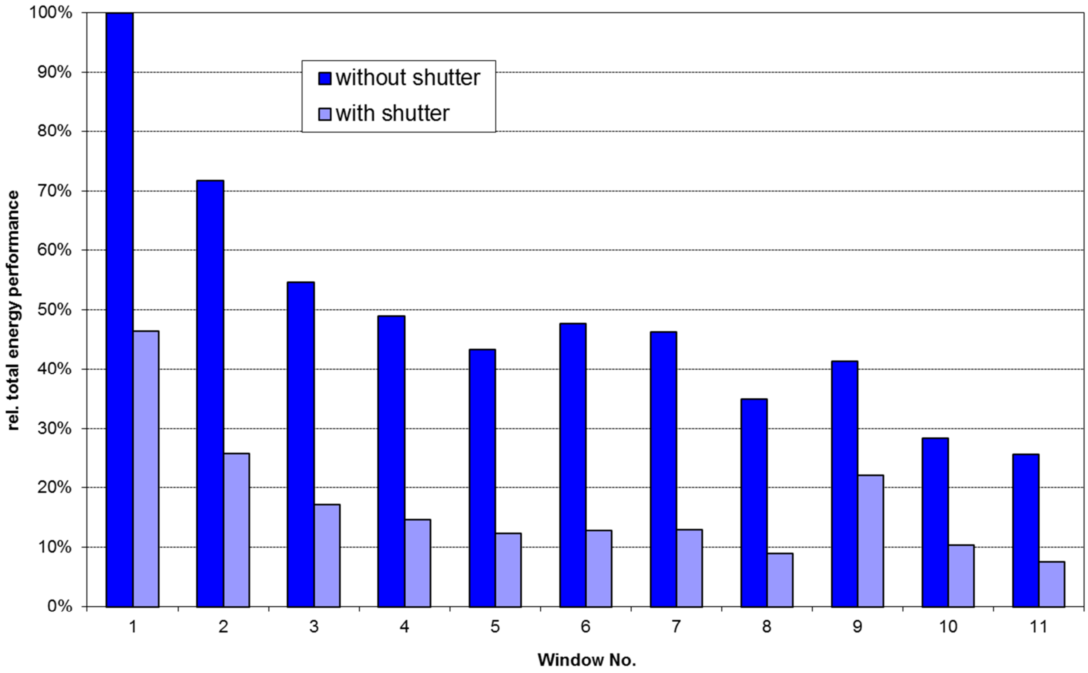


Figure A-78: Relative total energy demand for the Climate South; reduced ratio window area/floor area



A.4.4 No ventilative cooling

A.4.4.1. Calculated energy demand

Table A-45 Calculated energy demand – no ventilative cooling

No.	U_w in W/(m^2	g	Airtightness class	Energy use in kWh/(m^2 a)related to m^2 window area								
				Zone North			Zone Central			Zone South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5,8	0,85	2	599,1	36,6	635,7	362,8	51,5	414,3	74,1	230,1	304,1
2a	2,8	0,78	3	220,4	75,3	295,8	120,4	97,1	217,5	8,4	270,2	278,6
3a	1,7	0,65	4	98,4	80,2	178,6	47,7	101,1	148,9	-3,4	248,9	245,6
4a	1,3	0,60	4	65,9	79,6	145,5	28,9	99,9	128,8	-5,8	237,5	231,7
5a	1,0	0,55	4	42,7	76,3	118,9	15,8	95,8	111,6	-7,3	222,6	215,2
6a	0,8	0,60	4	19,7	95,4	115,1	1,1	116,7	117,9	-9,5	256,8	247,3
7a	1,0	0,58	4	39,9	83,7	123,5	13,6	104,1	117,6	-7,8	238,2	230,3
8a	0,6	0,47	4	12,7	68,7	81,4	-0,7	86,7	86,0	-9,0	195,5	186,5
9a	2,8	0,35	3	282,3	11,5	293,7	170,4	17,7	188,1	33,4	95,5	129,0
10a	1,3	0,35	4	95,3	29,0	124,3	51,3	40,2	91,5	0,9	117,3	118,2
11a	0,8	0,35	4	45,2	37,5	82,6	20,8	50,5	71,2	-4,9	128,8	123,9
with shutter												
1b	5,8	0,85	2	423,1	3,7	426,9	257,3	17,1	274,4	45,1	88,3	133,4
2b	2,8	0,78	3	164,4	22,0	186,3	88,5	39,0	127,6	3,0	97,1	100,1
3b	1,7	0,65	4	74,9	28,6	103,5	34,5	43,1	77,5	-5,1	90,1	85,0
4b	1,3	0,60	4	51,4	29,7	81,2	20,8	43,1	64,0	-6,8	86,1	79,3
5b	1,0	0,55	4	33,8	29,2	63,0	10,9	41,9	52,8	-7,8	80,8	72,9
6b	0,8	0,60	4	13,9	41,9	55,8	-2,0	53,6	51,6	-9,7	96,9	87,2
7b	1,0	0,58	4	31,0	33,6	64,6	8,7	46,1	54,8	-8,3	87,5	79,2
8b	0,6	0,47	4	9,5	27,1	36,6	-2,4	38,8	36,4	-9,1	71,2	62,2
9b	2,8	0,35	3	224,5	0,2	224,7	137,7	3,6	141,3	25,7	35,6	61,3
10b	1,3	0,35	4	80,5	6,3	86,8	43,7	15,7	59,4	-0,1	40,5	40,4
11b	0,8	0,35	4	39,4	10,7	50,0	18,0	21,4	39,4	-5,1	44,2	39,1

Figure A-79: Absolute energy demand for heating and cooling for the Climate North, no ventilative cooling

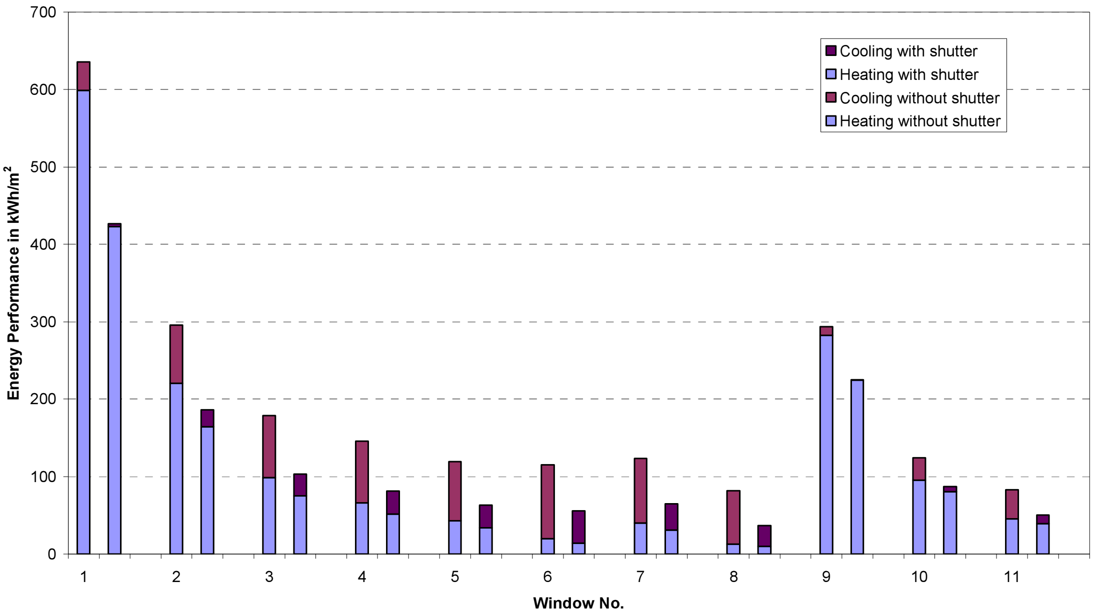


Figure A-80: Absolute energy demand for heating and cooling for the Climate Central, no ventilative cooling

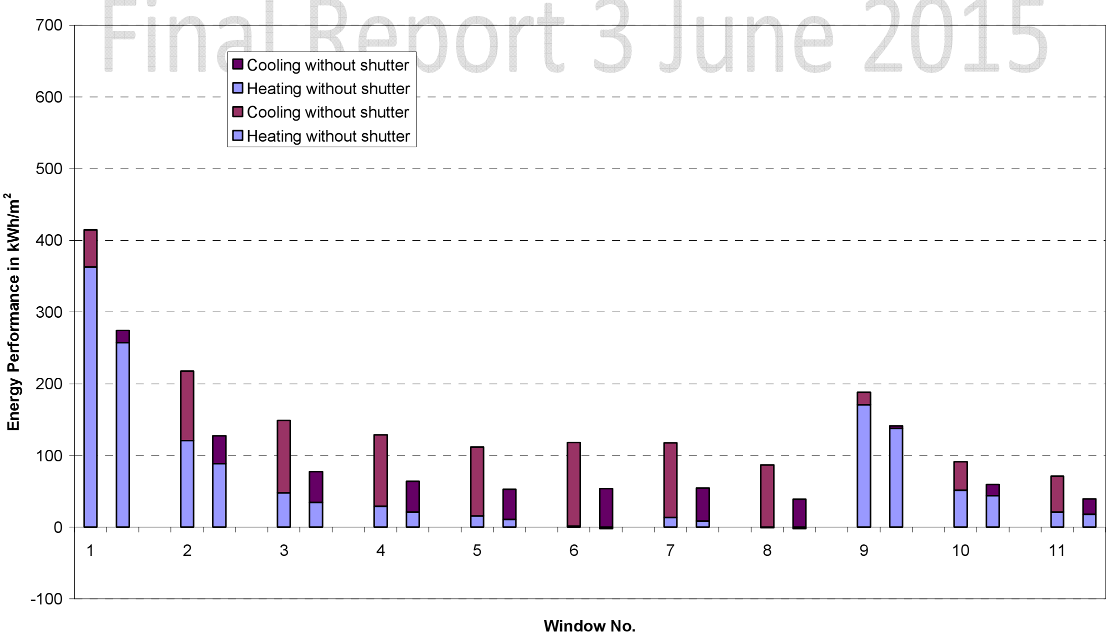
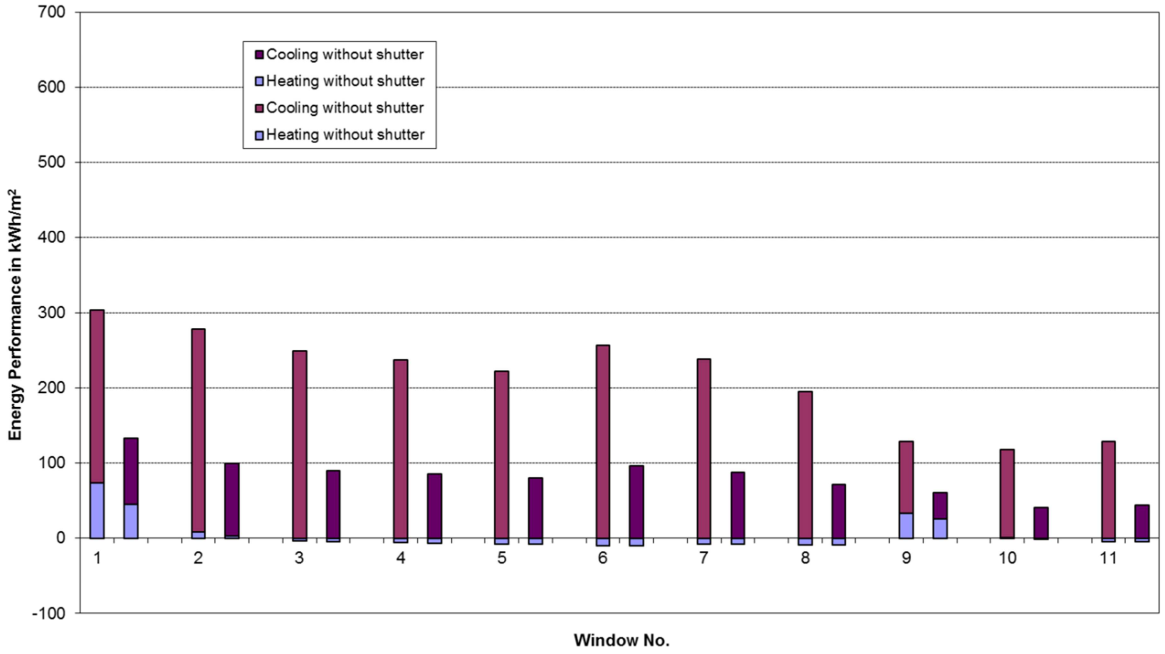


Figure A-81: Absolute energy demand for heating and cooling for the Climate South, no ventilative cooling



A.4.4.2. Relative total energy demand

Figure A-82: Relative total energy demand for the Climate North; no ventilative cooling

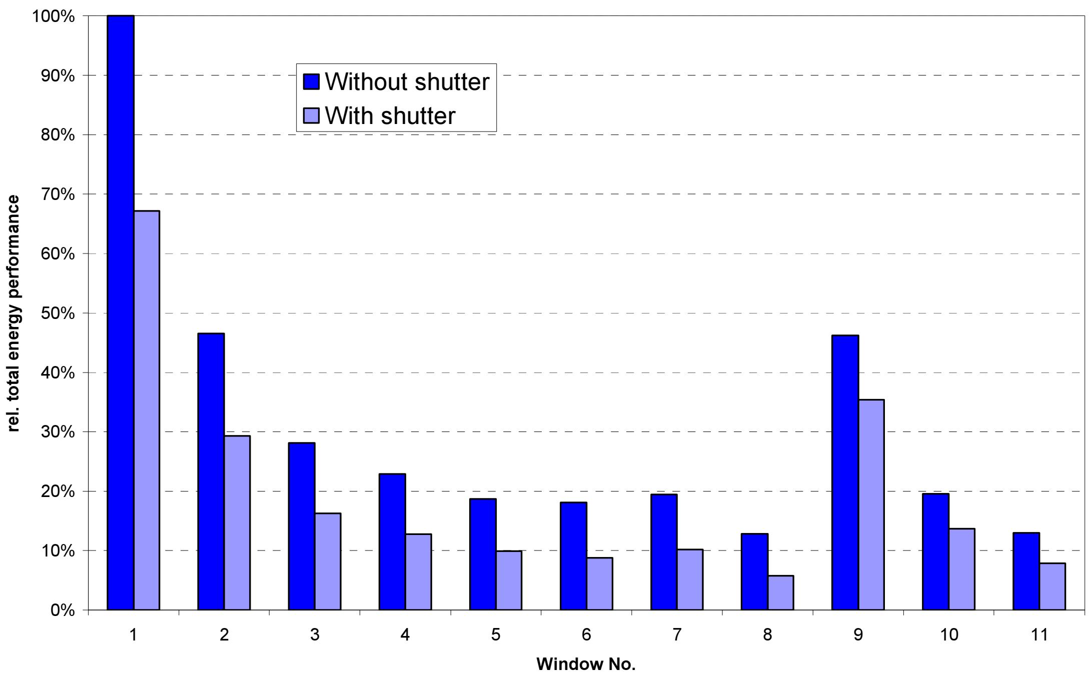


Figure A-83: Relative total energy demand for the Climate Central; no ventilative cooling

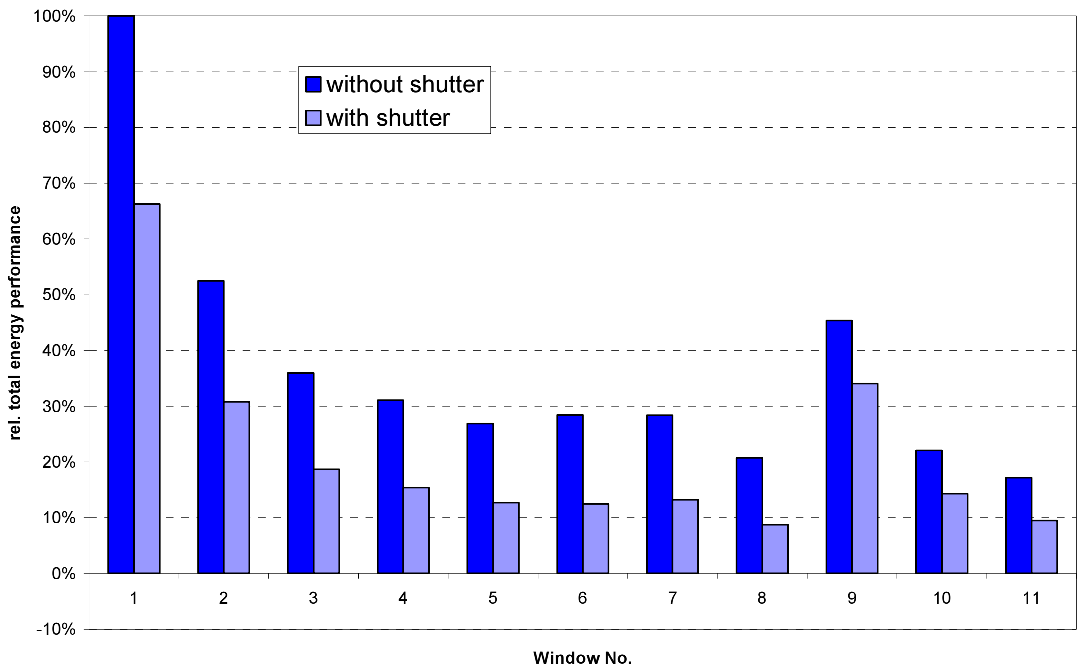
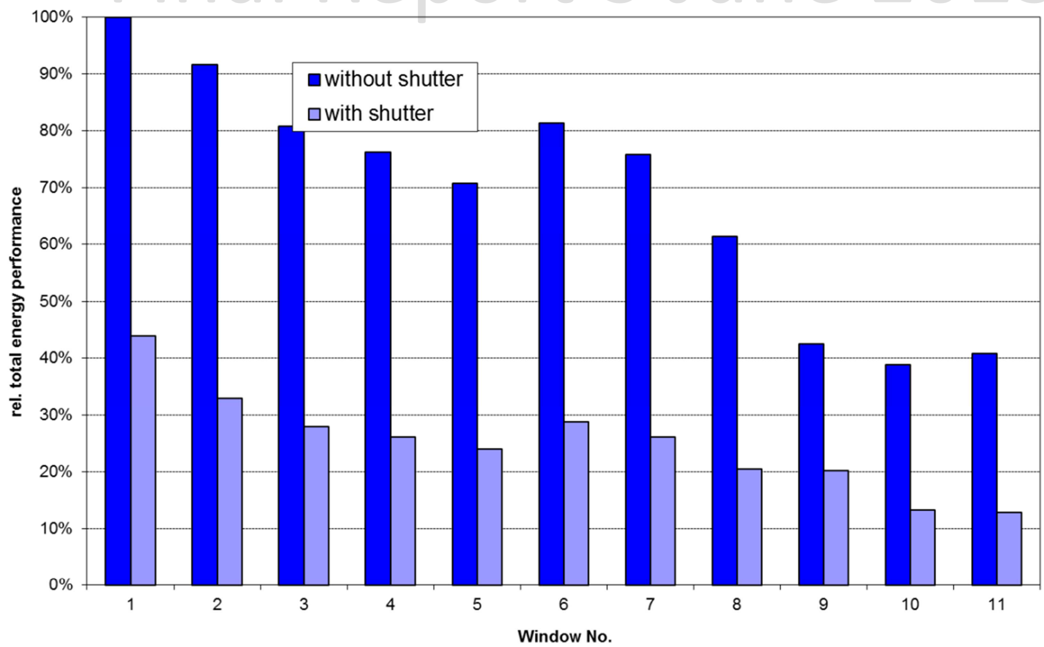


Figure A-84: Relative total energy demand for the Climate South; no ventilative cooling



A.4.4 "Office building"

A.4.4.1. Calculated energy demand

Table A-46 Calculated energy demand – Office building

No.	U_w in $W/(m^2$	g	Airtightness class	Energy use in kWh/(m² a)related to m² window area								
				Zone North			Zone Central			Zone South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5,8	0,85	2	589,0	42,4	631,5	359,9	56,4	416,3	79,3	217,7	297,0
2a	2,8	0,78	3	233,5	97,1	330,7	128,0	113,3	241,3	11,9	280,0	291,9
3a	1,7	0,65	4	117,5	111,5	229,0	58,4	125,4	183,8	2,2	273,1	275,3
4a	1,3	0,60	4	87,1	115,0	202,1	41,2	127,8	169,0	0,9	267,5	268,4
5a	1,0	0,55	4	65,2	114,6	179,8	29,4	126,6	155,9	0,4	256,9	257,3
6a	0,8	0,60	4	47,4	142,7	190,1	19,5	155,7	175,2	0,1	299,0	299,1
7a	1,0	0,58	4	63,9	124,3	188,2	28,4	136,8	165,2	0,3	274,2	274,5
8a	0,6	0,47	4	37,0	110,8	147,9	14,9	121,6	136,5	0,1	235,6	235,7
9a	2,8	0,35	3	276,9	9,4	286,2	162,6	11,9	174,6	26,8	86,3	113,1
10a	1,3	0,35	4	102,7	43,0	145,8	53,3	50,0	103,3	2,7	130,3	133,0
11a	0,8	0,35	4	58,9	61,6	120,4	27,7	69,8	97,5	0,4	153,6	154,0
with shutter												
1b	5,8	0,85	2	425,5	1,1	426,7	255,9	9,0	264,9	45,7	72,8	118,5
2b	2,8	0,78	3	180,1	41,6	221,7	96,3	47,6	143,9	6,5	103,6	110,0
3b	1,7	0,65	4	95,6	59,4	155,0	46,1	61,9	108,0	1,1	110,1	111,3
4b	1,3	0,60	4	73,8	64,2	138,0	34,0	65,6	99,7	0,5	111,0	111,6
5b	1,0	0,55	4	57,1	66,2	123,3	25,2	67,0	92,1	0,2	109,2	109,5
6b	0,8	0,60	4	42,3	88,2	130,5	17,0	88,4	105,3	0,1	134,3	134,4
7b	1,0	0,58	4	55,8	73,2	129,0	24,2	73,8	98,0	0,2	118,2	118,5
8b	0,6	0,47	4	34,0	67,3	101,2	13,4	67,7	81,1	0,0	104,7	104,7
9b	2,8	0,35	3	220,8	-9,2	211,6	129,0	-8,0	121,0	17,9	19,3	37,2
10b	1,3	0,35	4	88,4	14,5	102,9	45,1	16,3	61,4	1,8	42,3	44,0
11b	0,8	0,35	4	39,1	38,9	78,0	24,7	31,7	56,4	0,3	58,9	59,2

No.	U_w in $W/(m^2$	g	Airtightness class	Energy use in kWh/(m² a)related to m² window area								
				Zone North			Zone Central			Zone South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5,8	0,85	2	1167,1	84,1	1251,2	713,2	111,7	824,9	157,1	431,4	588,5
2a	2,8	0,78	3	462,7	192,5	655,2	253,7	224,5	478,2	23,6	554,7	578,3
3a	1,7	0,65	4	232,8	220,9	453,8	115,7	248,4	364,1	4,3	541,2	545,5
4a	1,3	0,60	4	172,6	227,8	400,4	81,6	253,3	334,9	1,7	530,1	531,8
5a	1,0	0,55	4	129,3	227,0	356,3	58,2	250,8	308,9	0,8	509,1	509,8
6a	0,8	0,60	4	94,0	282,7	376,7	38,6	308,5	347,1	0,2	592,5	592,6
7a	1,0	0,58	4	126,6	246,3	372,9	56,3	271,1	327,4	0,7	543,3	544,0
8a	0,6	0,47	4	73,3	219,6	293,0	29,5	240,9	270,4	0,1	466,9	467,0
9a	2,8	0,35	3	548,6	18,5	567,2	322,3	23,6	345,9	53,1	171,0	224,1
10a	1,3	0,35	4	203,6	85,2	288,8	105,7	99,1	204,8	5,3	258,3	263,6
11a	0,8	0,35	4	116,7	122,0	238,6	54,9	138,3	193,2	0,9	304,3	305,2
with shutter												
1b	5,8	0,85	2	843,2	2,2	845,4	507,1	17,8	525,0	90,6	144,3	234,9
2b	2,8	0,78	3	356,9	82,3	439,2	190,8	94,3	285,1	12,8	205,2	218,0
3b	1,7	0,65	4	189,5	117,7	307,1	91,4	122,6	214,0	2,3	218,2	220,5
4b	1,3	0,60	4	146,2	127,3	273,5	67,4	130,1	197,5	1,1	220,0	221,1
5b	1,0	0,55	4	113,1	131,1	244,2	49,8	132,7	182,5	0,5	216,5	217,0
6b	0,8	0,60	4	83,7	174,8	258,5	33,6	175,1	208,7	0,1	266,1	266,2
7b	1,0	0,58	4	110,6	145,0	255,6	48,0	146,2	194,3	0,4	234,3	234,7
8b	0,6	0,47	4	67,3	133,3	200,6	26,6	134,1	160,7	0,1	207,4	207,5
9b	2,8	0,35	3	437,5	-18,3	419,2	255,6	-15,8	239,8	35,5	38,2	73,8
10b	1,3	0,35	4	175,1	28,7	203,9	89,5	32,2	121,7	3,5	83,7	87,3
11b	0,8	0,35	4	77,5	77,1	154,6	49,0	62,9	111,8	0,7	116,6	117,3

Figure A-85: Absolute energy demand for heating and cooling for the Climate North, Office building

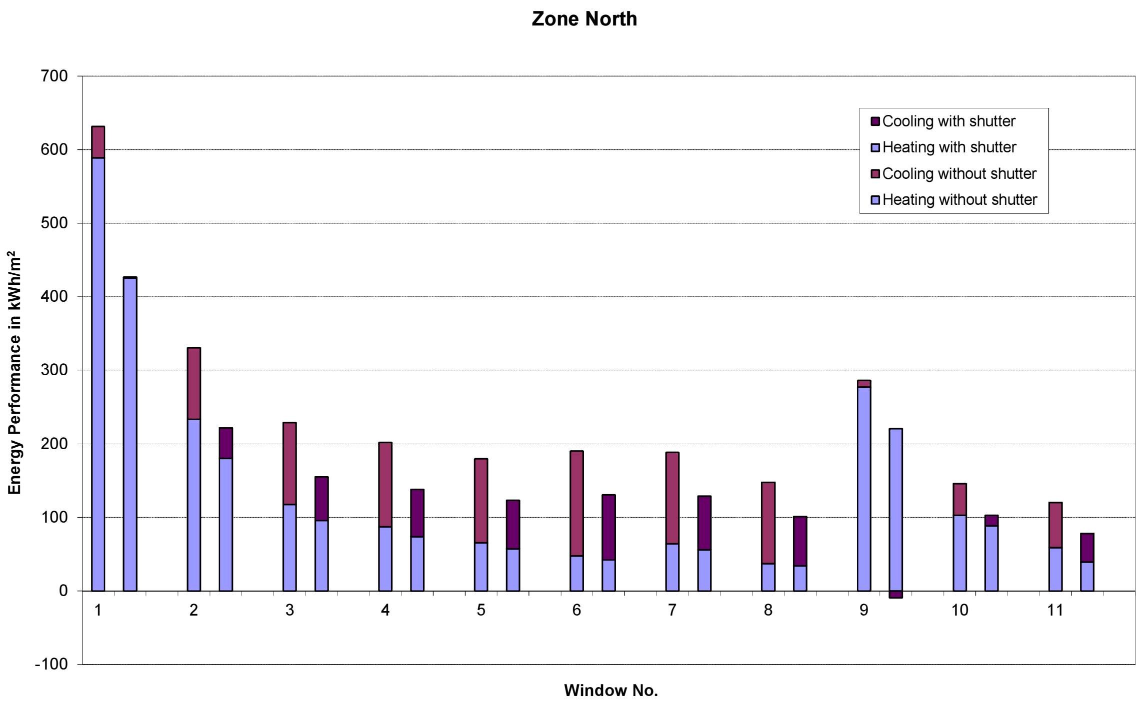


Figure A-86: Absolute energy demand for heating and cooling for the Climate Central, Office building

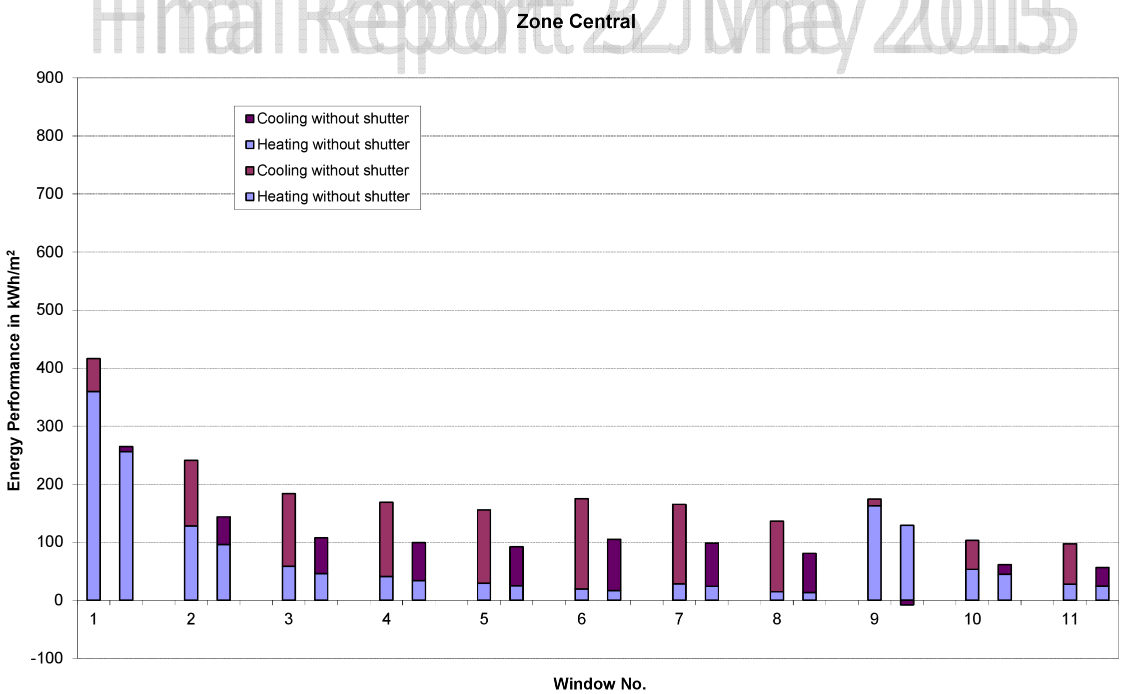
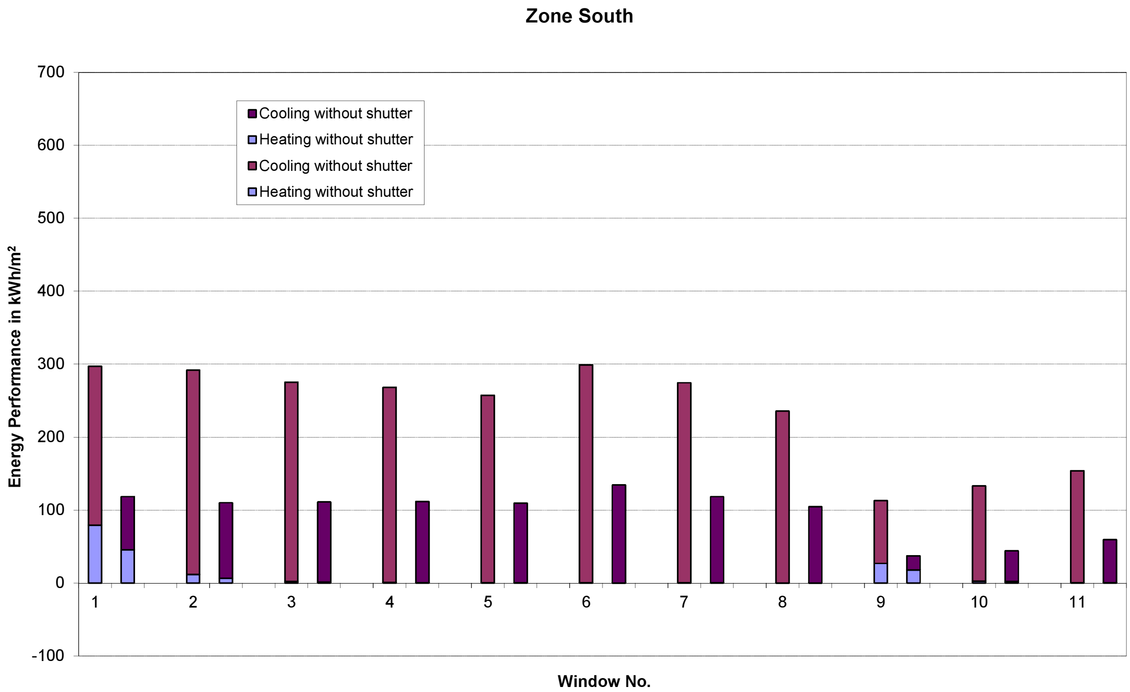


Figure A-87: Absolute energy demand for heating and cooling for the Climate South Office building



A.4.4.2. Relative total energy demand

Figure A-88: Relative total energy demand for the Climate North; Office building

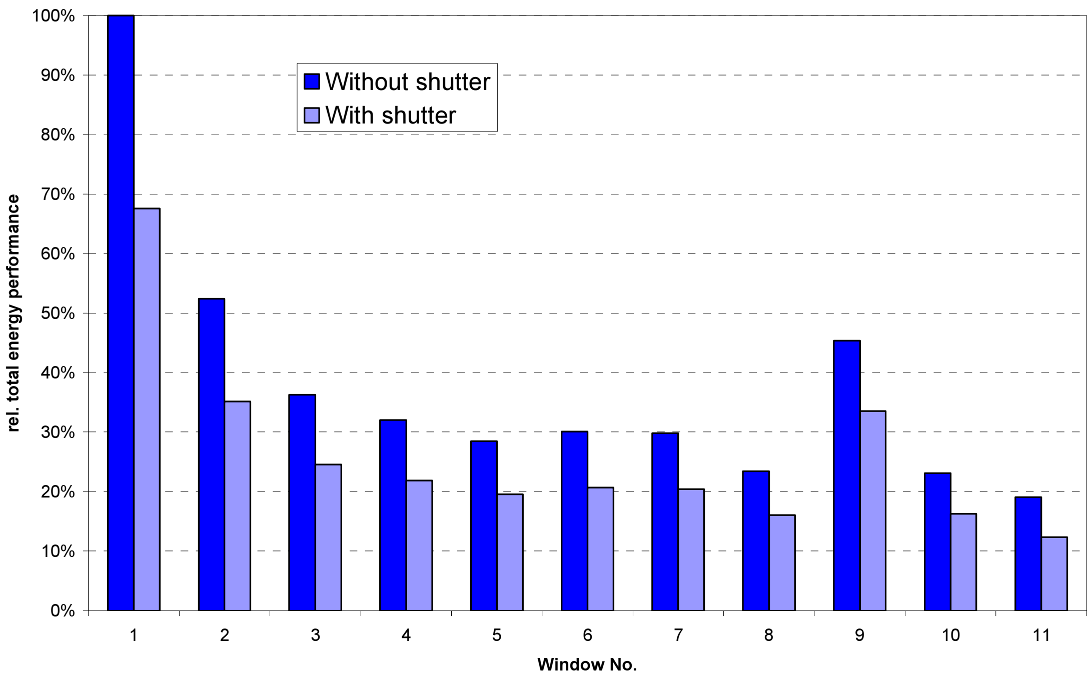


Figure A-89: Relative total energy demand for the Climate Central; Office building

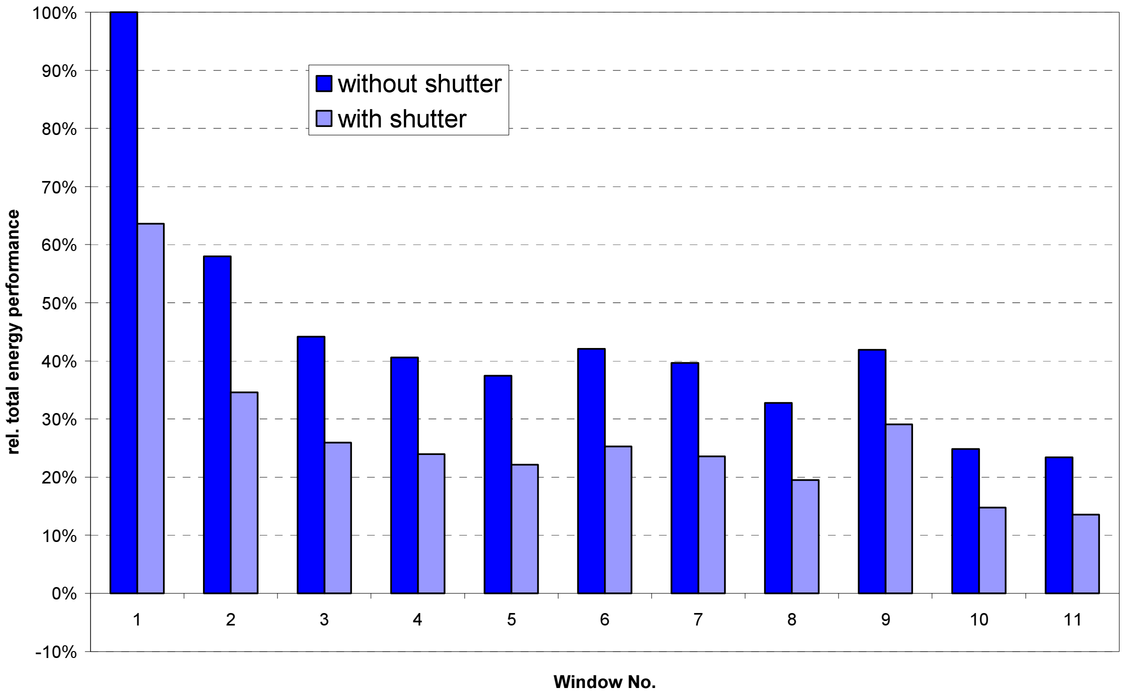
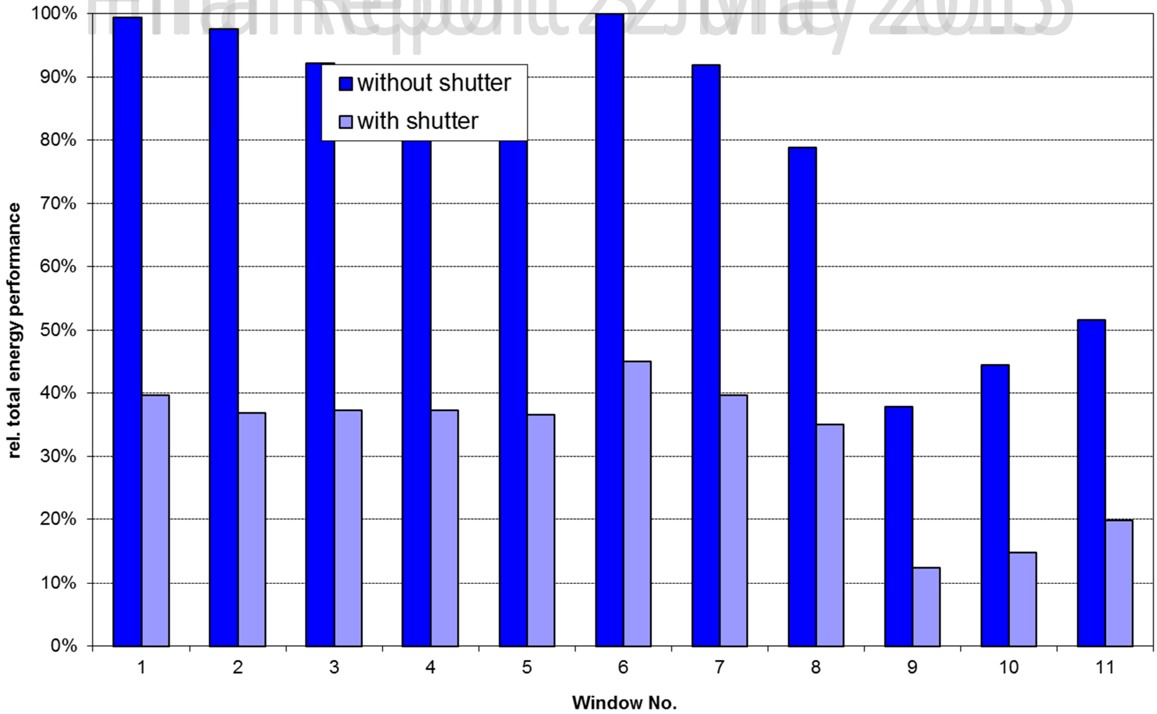


Figure A-90: Relative total energy demand for the Climate South; Office building



ANNEX B
SENSITIVITY OF THE ENERGY PERFORMANCE OF WINDOWS FOR ORIENTATION CALCULOATED WITH THE SINGLE ROOM MODEL

This sections shows the results when the performance of the façade window is not averaged over the four orientations. The boundary conditions are: single room model, window-to-floor ratio 20%, overall U_{env} = 0.8, ventilative cooling assumed, for three climate conditions.

NORTH

Table 47 Façade window facing NORTH

No.	U_w	g	Air-tight	Energy use in kWh/(m² a)related to m² window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	683.6	1.9	685.5	426.7	11.6	438.3	111.6	113.4	225.0
2a	2.8	0.78	3	281.2	2.7	283.9	163.6	14.1	177.6	28.2	106.6	134.9
3a	1.7	0.65	4	144.2	2.2	146.3	78.0	11.8	89.8	8.8	90.1	98.9
4a	1.3	0.60	4	106.7	1.9	108.6	55.3	10.8	66.1	5.1	83.7	88.8
5a	1.0	0.55	4	79.3	1.6	80.9	39.0	9.7	48.7	2.9	77.0	79.9
6a	0.8	0.60	4	55.2	2.1	57.3	23.2	11.8	35.0	0.9	84.9	85.7
7a	1.0	0.58	4	77.2	1.8	79.0	37.2	10.7	47.8	2.6	81.4	84.0
8a	0.6	0.47	4	43.5	1.2	44.7	18.2	7.8	26.0	0.7	66.0	66.7
9a	2.8	0.35	3	319.5	0.4	319.9	198.9	3.5	202.4	43.8	48.5	92.3
10a	1.3	0.35	4	126.0	0.6	126.5	73.0	4.3	77.2	10.2	47.9	58.1
11a	0.8	0.35	4	73.4	0.6	74.0	39.2	4.6	43.8	3.9	48.3	52.2
with shutter												
1b	5.8	0.85	2	502.6	1.4	504.0	308.0	12.3	320.3	68.8	117.1	185.9
2b	2.8	0.78	3	222.9	1.7	224.5	126.5	13.3	139.8	18.5	106.4	124.9
3b	1.7	0.65	4	119.2	1.3	120.6	62.5	10.8	73.4	6.0	88.8	94.8
4b	1.3	0.60	4	91.2	1.2	92.4	45.8	9.9	55.6	3.7	82.1	85.8
5b	1.0	0.55	4	69.7	1.0	70.7	33.2	8.8	42.0	2.2	75.3	77.5
6b	0.8	0.60	4	48.9	1.2	50.2	19.5	10.5	30.0	0.4	82.8	83.3
7b	1.0	0.58	4	67.6	1.1	68.7	31.4	9.6	41.0	1.8	79.6	81.4
8b	0.6	0.47	4	39.8	0.8	40.6	16.0	7.0	23.1	0.4	64.3	64.7
9b	2.8	0.35	3	260.0	0.3	260.3	160.2	3.5	163.8	32.3	49.1	81.4
10b	1.3	0.35	4	110.3	0.4	110.7	63.1	4.0	67.1	8.1	47.2	55.3
11b	0.8	0.35	4	67.0	0.4	67.4	35.2	4.3	39.5	3.3	47.2	50.5

Table 48 Façade window facing NORTH / ranked

No.	U_w	g	RANKED								
			Climate North			Climate Central			Climate South		
			Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter											
1a	5.8	0.85	11	7	11	11	8	11	11	11	11
2a	2.8	0.78	9	11	9	9	11	9	9	10	10
3a	1.7	0.65	8	10	8	8	10	8	7	9	9
4a	1.3	0.60	6	8	6	6	7	6	6	7	7
5a	1.0	0.55	5	5	5	4	5	5	4	5	4
6a	0.8	0.60	2	9	2	2	9	2	2	8	6
7a	1.0	0.58	4	6	4	3	6	4	3	6	5
8a	0.6	0.47	1	4	1	1	4	1	1	4	3
9a	2.8	0.35	10	1	10	10	1	10	10	3	8
10a	1.3	0.35	7	2	7	7	2	7	8	1	2
11a	0.8	0.35	3	3	3	5	3	3	5	2	1
with shutter											
1b	5.8	0.85	11	10	11	11	10	11	11	11	11
2b	2.8	0.78	9	11	9	9	11	9	9	10	10
3b	1.7	0.65	8	9	8	7	9	8	7	9	9
4b	1.3	0.60	6	7	6	6	7	6	6	7	8
5b	1.0	0.55	5	5	5	4	5	5	4	5	4
6b	0.8	0.60	2	8	2	2	8	2	2	8	7
7b	1.0	0.58	4	6	4	3	6	4	3	6	6
8b	0.6	0.47	1	4	1	1	4	1	1	4	3
9b	2.8	0.35	10	1	10	10	1	10	10	3	5
10b	1.3	0.35	7	2	7	8	2	7	8	1	2
11b	0.8	0.35	3	3	3	5	3	3	5	2	1

EAST

Table 49 Façade window facing EAST

No.	U_w	g	Air-tight	Energy use in kWh/(m^2 a)related to m^2 window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	608.9	19.7	628.6	372.9	45.1	418.1	63.5	260.9	324.4
2a	2.8	0.78	3	225.7	28.6	254.2	126.1	56.6	182.8	7.9	260.6	268.5
3a	1.7	0.65	4	100.6	22.5	123.1	50.8	46.4	97.2	-0.1	220.8	220.7
4a	1.3	0.60	4	67.0	19.6	86.6	31.1	41.8	72.9	-1.5	204.6	203.1
5a	1.0	0.55	4	43.0	16.3	59.4	17.3	36.7	54.0	-2.3	187.6	185.3
6a	0.8	0.60	4	18.5	21.9	40.4	2.3	45.1	47.4	-3.2	209.1	205.9
7a	1.0	0.58	4	39.9	19.0	58.9	15.2	40.8	56.0	-2.5	199.3	196.9
8a	0.6	0.47	4	12.3	11.5	23.7	0.1	28.5	28.5	-3.0	159.5	156.6
9a	2.8	0.35	3	285.3	2.8	288.1	174.6	10.2	184.8	26.7	108.0	134.7
10a	1.3	0.35	4	96.8	4.1	100.9	53.8	13.6	67.4	2.7	112.3	114.9
11a	0.8	0.35	4	46.2	4.7	50.8	22.1	15.0	37.1	-0.7	114.2	113.5
with shutter												
1b	5.8	0.85	2	424.9	0.9	425.8	255.7	12.4	268.1	31.8	86.8	118.6
2b	2.8	0.78	3	167.4	1.1	168.4	90.7	13.6	104.3	2.9	76.4	79.2
3b	1.7	0.65	4	75.8	0.8	76.6	36.3	10.9	47.2	-1.4	63.1	61.7
4b	1.3	0.60	4	51.6	0.7	52.3	22.3	9.8	32.1	-2.1	58.1	56.0
5b	1.0	0.55	4	33.5	0.6	34.0	12.0	8.7	20.7	-2.6	53.2	50.7
6b	0.8	0.60	4	12.3	0.8	13.0	-1.3	10.5	9.3	-3.3	58.4	55.1
7b	1.0	0.58	4	30.3	0.7	31.0	9.8	9.6	19.4	-2.8	56.2	53.5
8b	0.6	0.47	4	8.6	0.4	9.0	-1.8	7.0	5.1	-3.1	45.4	42.2
9b	2.8	0.35	3	224.5	0.2	224.6	136.6	3.7	140.3	17.3	36.1	53.4
10b	1.3	0.35	4	81.0	0.2	81.2	44.5	4.2	48.7	1.5	33.7	35.2
11b	0.8	0.35	4	39.7	0.2	39.9	18.5	4.4	22.9	-1.1	33.4	32.4

Table 50 Façade window facing EAST / ranked

No.	U_w	g	RANKED								
			Climate North			Climate Central			Climate South		
			Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter											
1a	5.8	0.85	11	8	11	11	8	11	11	11	11
2a	2.8	0.78	9	11	9	9	11	9	9	10	10
3a	1.7	0.65	8	10	8	7	10	8	7	9	9
4a	1.3	0.60	6	7	6	6	7	7	5	7	7
5a	1.0	0.55	4	5	5	4	5	4	4	5	5
6a	0.8	0.60	2	9	2	2	9	3	1	8	8
7a	1.0	0.58	3	6	4	3	6	5	3	6	6
8a	0.6	0.47	1	4	1	1	4	1	2	4	4
9a	2.8	0.35	10	1	10	10	1	10	10	1	3
10a	1.3	0.35	7	2	7	8	2	6	8	2	2
11a	0.8	0.35	5	3	3	5	3	2	6	3	1
with shutter											
1b	5.8	0.85	11	10	11	11	10	11	11	11	11
2b	2.8	0.78	9	11	9	9	11	9	9	10	10
3b	1.7	0.65	7	9	7	7	9	7	6	9	9
4b	1.3	0.60	6	7	6	6	7	6	5	7	8
5b	1.0	0.55	4	5	4	4	5	4	4	5	4
6b	0.8	0.60	2	8	2	2	8	2	1	8	7
7b	1.0	0.58	3	6	3	3	6	3	3	6	6
8b	0.6	0.47	1	4	1	1	4	1	2	4	3
9b	2.8	0.35	10	1	10	10	1	10	10	3	5
10b	1.3	0.35	8	2	8	8	2	8	8	2	2
11b	0.8	0.35	5	3	5	5	3	5	7	1	1

SOUTH

Table 51 Façade window facing SOUTH

No.	U_w	g	Air-tight class	Energy use in kWh/(m² a)related to m² window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	514.5	20.3	534.8	297.4	35.7	333.1	20.6	236.5	257.1
2a	2.8	0.78	3	144.9	28.8	173.6	67.2	44.3	111.5	-2.5	244.1	241.6
3a	1.7	0.65	4	35.4	22.2	57.7	4.0	36.2	40.2	-3.6	205.0	201.4
4a	1.3	0.60	4	7.3	19.3	26.6	-11.8	32.6	20.8	-3.7	188.6	184.9
5a	1.0	0.55	4	-11.8	16.1	4.3	-22.0	28.6	6.6	-3.7	171.3	167.7
6a	0.8	0.60	4	-36.3	21.6	-14.7	-37.4	35.1	-2.3	-3.7	194.5	190.8
7a	1.0	0.58	4	-16.3	18.7	2.5	-25.3	31.8	6.5	-3.7	183.7	180.0
8a	0.6	0.47	4	-35.3	11.4	-24.0	-34.3	22.4	-12.0	-3.7	144.1	140.5
9a	2.8	0.35	3	241.9	3.0	244.9	138.7	8.8	147.6	7.8	94.7	102.4
10a	1.3	0.35	4	55.6	4.2	59.8	22.7	11.2	34.0	-3.1	99.1	96.0
11a	0.8	0.35	4	6.0	4.8	10.8	-7.0	12.2	5.2	-3.6	101.2	97.6
with shutter												
1b	5.8	0.85	2	333.9	0.8	334.7	198.2	9.9	208.2	5.5	80.1	85.6
2b	2.8	0.78	3	88.7	1.0	89.7	36.9	10.9	47.8	-3.1	72.8	69.7
3b	1.7	0.65	4	12.0	0.8	12.8	-8.4	9.0	0.6	-3.6	60.8	57.1
4b	1.3	0.60	4	-7.1	0.7	-6.4	-19.4	8.3	-11.1	-3.6	56.3	52.6
5b	1.0	0.55	4	-20.8	0.6	-20.2	-26.5	7.4	-19.1	-3.7	51.6	48.0
6b	0.8	0.60	4	-42.1	0.7	-41.3	-40.4	8.8	-31.6	-3.7	56.8	53.1
7b	1.0	0.58	4	-25.1	0.6	-24.4	-29.8	8.1	-21.7	-3.7	54.6	50.9
8b	0.6	0.47	4	-38.6	0.4	-38.2	-35.8	6.1	-29.7	-3.7	44.2	40.5
9b	2.8	0.35	3	184.5	0.1	184.7	111.4	3.2	114.6	3.5	34.1	37.5
10b	1.3	0.35	4	41.1	0.2	41.3	17.2	3.7	20.9	-3.2	32.6	29.4
11b	0.8	0.35	4	0.5	0.2	0.7	-8.9	3.9	-5.0	-3.5	32.6	29.0

Table 52 Façade window facing SOUTH / ranked

No.	U_w	g	RANKED								
			Climate North			Climate Central			Climate South		
			Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter											
1a	5.8	0.85	11	8	11	11	9	11	11	10	11
2a	2.8	0.78	9	11	9	9	11	9	9	11	10
3a	1.7	0.65	7	10	7	7	10	8	6	9	9
4a	1.3	0.60	6	7	6	5	7	6	5	7	7
5a	1.0	0.55	4	5	4	4	5	5	1	5	5
6a	0.8	0.60	1	9	2	1	8	2	1	8	8
7a	1.0	0.58	3	6	3	3	6	4	1	6	6
8a	0.6	0.47	2	4	1	2	4	1	1	4	4
9a	2.8	0.35	10	1	10	10	1	10	10	1	3
10a	1.3	0.35	8	2	8	8	2	7	8	2	1
11a	0.8	0.35	5	3	5	6	3	3	7	3	2
with shutter											
1b	5.8	0.85	11	10	11	11	10	11	11	11	11
2b	2.8	0.78	9	11	9	9	11	9	9	10	10
3b	1.7	0.65	7	9	7	7	9	7	6	9	9
4b	1.3	0.60	5	7	5	5	7	5	5	7	7
5b	1.0	0.55	4	5	4	4	5	4	1	5	5
6b	0.8	0.60	1	8	1	1	8	1	1	8	8
7b	1.0	0.58	3	6	3	3	6	3	1	6	6
8b	0.6	0.47	2	4	2	2	4	2	1	4	4
9b	2.8	0.35	10	1	10	10	1	10	10	3	3
10b	1.3	0.35	8	2	8	8	2	8	8	2	2
11b	0.8	0.35	6	3	6	6	3	6	7	1	1

WEST

Table 53 Façade window facing WEST

No.	U_w	g	Air-tight class	Energy use in kWh/(m^2 a)related to m^2 window area								
				Climate North			Climate Central			Climate South		
				Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter												
1a	5.8	0.85	2	603.9	17.7	621.7	363.3	37.9	401.2	60.7	262.8	323.5
2a	2.8	0.78	3	219.7	24.2	243.9	118.8	46.6	165.4	6.5	261.2	267.8
3a	1.7	0.65	4	95.9	18.9	114.8	45.8	38.3	84.2	-0.6	221.5	220.9
4a	1.3	0.60	4	62.8	16.6	79.3	26.8	34.6	61.4	-1.9	205.3	203.4
5a	1.0	0.55	4	39.2	13.9	53.1	13.5	30.5	43.9	-2.6	188.2	185.6
6a	0.8	0.60	4	14.9	18.4	33.3	-1.9	37.4	35.5	-3.4	209.5	206.1
7a	1.0	0.58	4	35.9	16.1	52.0	11.1	33.8	44.9	-2.9	199.9	197.0
8a	0.6	0.47	4	9.1	9.9	19.0	-3.2	23.8	20.5	-3.3	160.4	157.1
9a	2.8	0.35	3	283.0	2.7	285.7	170.3	9.3	179.6	25.4	109.3	134.7
10a	1.3	0.35	4	94.0	3.9	97.9	50.1	11.8	62.0	2.4	113.3	115.7
11a	0.8	0.35	4	43.4	4.4	47.8	19.0	12.9	31.9	-1.0	115.2	114.3
with shutter												
1b	5.8	0.85	2	428.7	0.8	429.5	265.8	10.7	276.5	37.2	81.2	118.4
2b	2.8	0.78	3	164.5	1.1	165.6	91.7	11.8	103.5	2.8	74.7	77.5
3b	1.7	0.65	4	72.8	0.9	73.6	34.9	9.7	44.7	-1.5	62.6	61.0
4b	1.3	0.60	4	48.8	0.8	49.6	20.6	8.9	29.4	-2.4	58.0	55.6
5b	1.0	0.55	4	30.9	0.6	31.5	10.2	8.0	18.1	-2.8	53.3	50.5
6b	0.8	0.60	4	9.4	0.9	10.3	-4.1	9.5	5.4	-3.5	58.6	55.1
7b	1.0	0.58	4	27.5	0.7	28.2	7.6	8.7	16.2	-3.0	56.3	53.3
8b	0.6	0.47	4	6.4	0.4	6.9	-3.6	6.6	3.0	-3.2	45.6	42.3
9b	2.8	0.35	3	227.2	0.1	227.3	142.4	3.5	145.8	19.2	34.4	53.7
10b	1.3	0.35	4	80.5	0.2	80.7	46.3	4.0	50.2	1.5	33.4	34.9
11b	0.8	0.35	4	38.7	0.2	38.9	18.9	4.2	23.1	-1.1	33.5	32.4

Table 54 Façade window facing WEST / ranked

No.	U_w	g	RANKED								
			Climate North			Climate Central			Climate South		
			Heat	Cool	Total	Heat	Cool	Total	Heat	Cool	Total
Without shutter											
1a	5.8	0.85	11	8	11	11	9	11	11	11	11
2a	2.8	0.78	9	11	9	9	11	9	9	10	10
3a	1.7	0.65	8	10	8	7	10	8	7	9	9
4a	1.3	0.60	6	7	6	6	7	6	5	7	7
5a	1.0	0.55	4	5	5	4	5	4	4	5	5
6a	0.8	0.60	2	9	2	2	8	3	1	8	8
7a	1.0	0.58	3	6	4	3	6	5	3	6	6
8a	0.6	0.47	1	4	1	1	4	1	2	4	4
9a	2.8	0.35	10	1	10	10	1	10	10	1	3
10a	1.3	0.35	7	2	7	8	2	7	8	2	2
11a	0.8	0.35	5	3	3	5	3	2	6	3	1
with shutter											
1b	5.8	0.85	11	8	11	11	10	11	11	11	11
2b	2.8	0.78	9	11	9	9	11	9	9	10	10
3b	1.7	0.65	7	9	7	7	9	7	6	9	9
4b	1.3	0.60	6	7	6	6	7	6	5	7	8
5b	1.0	0.55	4	5	4	4	5	4	4	5	4
6b	0.8	0.60	2	10	2	1	8	2	1	8	7
7b	1.0	0.58	3	6	3	3	6	3	3	6	5
8b	0.6	0.47	1	4	1	2	4	1	2	4	3
9b	2.8	0.35	10	1	10	10	1	10	10	3	6
10b	1.3	0.35	8	2	8	8	2	8	8	1	2
11b	0.8	0.35	5	3	5	5	3	5	7	2	1